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**MASTER OF SCIENCE BY RESEARCH**

# The effects of hand and foot cooling on thermoregulation during upper body exercise in the heat

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# The Effects of Hand and Foot Cooling On Thermoregulation During Upper Body Exercise In The Heat

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# Abstract

Intro: Upper body exercise provides a number of different physiological and thermoregulatory challenges compared to lower body exercise and these are accentuated during exercise in heated environments. Hand and foot cooling have been shown to alleviate thermal strain and reduce core temperature. Hand cooling has also been shown to improve endurance exercise performance in the heat.

Aims: This study aims to assess the effects of hand and foot cooling on thermoregulation during upper body exercise performance in the heat.

Methods: Seven participants performed an incremental $\dot{V}O_{2pk}$ test to determine peak oxygen uptake ($\dot{V}O_{2pk}$) and peak power output ($W_{pk}$). The three experimental trials began with two 15 minute resting periods in the cool and the heat (37.7 ± 0.2°C) followed by 20 minutes of arm cranking exercise at 60% $W_{pk}$ in the heat. Participants then underwent 15 minutes of cooling, during which the hands (HC) or the feet (FC) were submerged in water (10°C), or a no cooling control (NC). Following cooling, participants performed a performance trial to exhaustion at 75% $W_{pk}$.

Results: No significant interactions between trials were observed for core temperature measurements ($P>0.05$). However, there was a trend for aural temperature ($T_{au}$) to decrease more during HC (0.9 ± 0.3°C) than FC (0.3 ± 0.3°C) or NC (0.5 ± 0.5°C). Heat loss was observed to be significantly greater from the hands (139.5 ± 16.5 W) than from the feet 121 ± 8.8 W) during cooling ($P<0.05$). In addition, upper arm skin temperature ($T_{arm}$) was lower during HC (1.7 ± 0.6°C) than FC (0.8 ± 0.4°C) or NC (0.3 ± 0.5°C) ($P<0.05$).

Cooling did not result in significant improvements in upper body endurance performance compared to NC ($P>0.05$).

Conclusions: HC results in greater heat loss than FC and NC during 15 minutes of cooling in the heat. HC results in a lower $T_{arm}$ compared to FC and NC following 15 minutes of cooling. There is no difference in the changes in core temperature between HC, FC and NC during 15 minutes of cooling in the heat. Neither HC nor FC results in a significant improvement in upper body endurance performance in the heat compared to NC. However, small improvements in performance time can be seen following HC compared to NC.

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# 1.0 Introduction

Thermoregulation is an essential regulatory mechanism in the human body. Core temperature changes can significantly affect vital systems and processes through changes in blood flow (Deja et al., 2010), blood pressure (Karino et al., 1988; Armstrong et al., 2010), motor neuron activity (Nielsen and Nybo 2001; Nielsen and Nybo, 2003) and enzyme activity (Noakes, 1987) to name but a few. As such, there are a number of systems in place to counteract rises in core temperature in order to prevent damage to vital organs and systems.

Increases in core temperature may occur simply due to gains in heat via radiation from an increase in environmental temperature or by an increase in metabolic rate. Exercise instigates an increased energy demand from the working muscles requiring an increase in metabolic rate (Thomas et al., 1995; Kilpatrick et al., 2009). As energy production increases heat production also increases resulting in an increase in core temperature. An increase in core temperature will lead to an increase in cutaneous blood flow, resulting in loss of heat from the blood to the skin and via convection then to the environment returning cooler blood to the core. Sweat rates will also increase in order to lose heat from the skin via evaporative cooling. If exercising, blood vessels will vasodilate to increase blood flow to the working muscles, therefore attenuating increases in blood pressure, and increasing the rate of convective heat loss. These mechanisms are vital in order to maintain a stable internal environment and normal metabolic functioning. If this heat is not dissipated and core temperature continues to increase, exercise performance will be greatly compromised (Noonan et al., 2007; Cheuvront et al., 2010).

The combined effects of exercise and heat stress can significantly reduce exercise performance (Hargreaves, 2005). Consequently methods of counteracting detrimental effects are an essential area of investigation. A number of cooling methods have been investigated including whole body cooling (Booth et al., 1997; White et al., 2003), ice-vests (Duffield et al, 2003; Cheung and Robinson, 2004; Duffield et al., 2009), and hand or foot cooling (Livingstone et al., 1989; Livingstone et al., 1995; House et al., 1997; Goosey-Tolfrey et al., 2008). Each method poses its own practicality issues, particularly in a sporting context where opportunities to rest and engage in a cooling strategy may be limited. However, if significant physiological benefits are observed with cooling methods it does provide a possible rationale for prolonging exercise performance that would otherwise be hampered by heat strain.

Whilst the effects of hand and foot cooling have been previously studied there have been few applications of these methods in an exercise context with fewer still focussing on upper body exercise. Due to the nature of certain sports, rests can be frequent with a definite opportunity to employ cooling strategies. Cooling may also be of benefit in some sports where hyperthermia occurs due to the large amount of protective clothing worn throughout and the hot climates in which they are often played.

Upper body exercise is an important area of study for a number of populations, including rowing or paddling based athletes and wheelchair athletes, as their activities involve a greater proportion of upper body work than the traditional exercise modes of running and cycling. Furthermore, studies of the different cardiovascular and thermoregulatory effects between lower body and upper body exercise (Sawka et al., 1984; Pimental et al., 1984; Sawka, 1989) indicate that upper body exercise provide unique physiological responses and requires further research in order to gauge a clearer understanding of the mechanisms involved.

This study aims to assess the effects of hand and foot cooling on performance during upper body exercise in the heat. Currently, data for thermoregulation during upper body exercise is limited and has mainly been gathered for wheelchair populations with the majority of data available for able-bodied populations coming from control group data. As such, this is an area with large scope for investigation. In addition, upper body exercise performance following cooling has not been investigated in able bodied populations, however data has been recorded for wheelchair populations (Goosey-Tolfrey et al., 2008).

# 2.0 Literature Review

This literature review will outline the thermoregulatory effects of exercise in cool and high ambient temperatures along with the need for cooling in order to maintain body function. The fundamental role of the microvasculature in regulating core temperature and its importance during exercise and heat stress will also be covered. In addition, the different methods of cooling that have previously been studied will be analysed.

## 2.1 Thermoregulation

Thermoregulation describes the mechanisms by which the body seeks to maintain a stable internal temperature (Seeley et al., 2008). This requires a balance between heat loss and heat gain. When one begins to exceed the other then thermoregulatory mechanisms must be employed to counteract these changes. Core temperature is particularly important as most enzymes are temperature sensitive and the narrow ranges in which they function require a constant internal temperature to be maintained to avoid severe damage to body function (Fitts, 2008). Therefore core temperature is considered to be the major driving force in thermoregulation (Schlader et al., 2010).

### 2.1.i Body Temperature Control

Thermoregulation is controlled by the anterior hypothalamus (Carpenter, 2003). The hypothalamus receives information via the sympathetic and parasympathetic nervous systems from a variety of sources. The main source of stimulation is the temperature of the blood circulating the hypothalamus itself (Cabanac, 1975). As core temperature rises blood temperature will also increase. When the warmed blood reaches the hypothalamus the heat loss centre will be stimulated and initiate a cooling response. Firstly, vasodilation will occur in the arterioles and increase the blood flow through the cutaneous circulation

(Johnson and Park, 1979). This will increase the amount of blood flowing to the skin surface and enable a greater amount of heat to be lost to the environment. The increased thermal gradient between the skin and the environment will result in much more efficient heat dissipation. Cooled blood will then return to the core and help to lower core temperature (Fortney and Vroman, 1985). The hypothalamus will also stimulate sweat glands to increase sweat rates and therefore lose more heat via evaporative cooling (Gisolfi and Wenger, 1984). As cooled blood returning to the core begins to lower core temperature, the stimulation of the hypothalamus begins to decrease proportionally as do its associated responses. This is known as proportional control (Gisolfi and Wenger, 1984).

If core temperature were to decrease then the heat gain centre in the hypothalamus would be stimulated and a number of heat gain mechanisms would occur. The contracting stimulus to the walls of the peripheral arterioles in cutaneous circulation would increase resulting in vasoconstriction (Hammel et al., 1963). This will reduce the blood flow to the skin surface and reduce the amount of heat lost to the environment. If initiated, sweat rates would be decreased to reduce evaporative cooling and shivering would occur in order to provide more heat from muscle contractions.

### 2.1.ii Core Temperature

Resting core temperature in humans is ~37°C although different measurement sites may provide different values. For example Price and Mather (2004) reported resting rectal temperature measurements of 37.0 ± 0.7°C whilst aural temperature measurements read 36.4 ± 0.4°C. Rectal temperatures have also been observed at 37.6 ± 0.5°C (Livingstone et al., 1989). In addition, oesophageal temperature may read around 37.0°C (Wyss et al., 1975) and gastric measurements have reported temperatures at between 36.9°C and 37.3°C

(Goosey-Tolfrey et al., 2008). Rectal temperature is usually considered the most accurate and reliable method for resting individuals despite reported discomfort for the participants (Lim et al., 2008). Temperatures below 36°C or above 39°C are considered to be dangerous and are usually symptoms of illness (Axelrod and Diringer, 2008). However, during endurance exercise, particularly in high ambient temperatures, core temperature may be seen to rise as high as 40°C and even 42°C in long duration endurance events (Laursen et al., 2006; Ely et al., 2009). These increased core temperatures will elicit the aforementioned responses associated with increased heat dissipation but with possible local adaptations (Merla et al., 2010) depending on the type of exercise and the mass of exercising muscle (Sawka et al., 1984).

### 2.1.iii Blood Flow Responses

The cutaneous microcirculatory system serves many important functions within the human body. Along with its rudimentary purpose of the supply of nutrients to the epidermis and other peripheral cell networks, the microvasculature also has a vital role to play in the control of skin and core body temperature. The cutaneous microvasculature contains two important networks - the upper horizontal plexus and the lower horizontal plexus (Braverman, 2000). The former, containing the arterioles and venules of the epidermis, and the latter those of the subcutaneous fat and muscle cells are interconnected by a series of arterioles and venules (Fig. 2.1) (Braverman, 1989).

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Figure 2.1. The cutaneous microvasculature. E - epidermis; A - arteriole; V - venule; F - subcutaneous fat. (From Braverman, 1989)

The microcirculatory system is a major component in the control of body temperature. During exercise or hot ambient temperatures the core body temperature will gradually increase as a result of increased metabolic activity (Yokota et al., 2008). This increase in core temperature needs to be attenuated by dissipation of heat from the body to the environment which can be achieved via radiation, convection, conduction and evaporation from the skin. In order to increase heat dissipation from the skin the cutaneous arterioles will vasodilate, therefore increasing the blood flow to the epidermis (Stolwijk, 1977; Johnson and Kellogg, 2010). The warmed blood, carrying heat transferred from the body core, is then cooled as heat is lost from the skin to the environment and as the cooled blood returns to the central circulation it cools the body core (Plattner et al., 1996). Increasing blood flow to the epidermis also results in a greater temperature gradient between the skin surface and the environment (supposing that the environmental temperature is lower than that of the blood) and so not only can heat dissipated from a greater volume of blood per unit time, it can do so with greater efficiency (Johnson and Kellogg, 2010).

Skin blood flow is not only affected by changes in skin and core temperature but also by changes in blood pressure (Rowell et al., 1973). Increases in blood pressure are detected by baroreceptors which then instigate vasodilation in peripheral arterioles in order to reduce peripheral resistance and therefore reduce arterial pressure. Arterial pressure increases caused by passive heating can be dealt with in this way as increased skin blood flow would also allow increased heat dissipation as previously described. Should these pressure changes occur during exercise however, we are presented with another obstacle in that cutaneous vasodilation would be in direct competition with cutaneous vasoconstriction as blood needs to be redirected to the working muscles. Even during heating where the baroreceptor vasodilation response is triggered, the cutaneous vasculature still retains the ability to actively vasoconstrict in order to redirect blood flow (Johnson et al., 1973). This is incredibly important for high-intensity exercise in the heat as there is also be a continuous requirement for increased blood flow to working muscles.

When increasing vasodilation to the muscles in the exercising regions, there must be a decrease in flow elsewhere in the body to provide the extra flow. Vasoconstriction will occur in the areas that are not essential for the exercise being performed (eg. splanchnic circulation), thus resulting in reduced flow to less active areas of around 13% (Rowell et al., 1964) or up to 20% during heat stress (Rowell et al., 1965) and providing a larger volume of blood to the more active areas (Kenney and Ho, 1995). Indeed, estimated splanchnic flow has been shown to decrease by as much as 65% during prolonged leg exercise (Ahlborg and Felig, 1982). The redirection of blood away from non-exercising areas can indeed lead to decreases in skin temperature around the site (Sawka et al., 1984; Theisen et al., 2001), which will also attenuate exercise-induced temperature increases and local thermoregulatory differences.

Johnson and Rowell (1975) investigated skin and vascular responses to incremental leg exercise. Total forearm blood flow (TBF) was measured in this study and shown to significantly and progressively increase during exercise whereas the forearm muscle blood flow (MBF) was shown to decrease. The assumption was therefore made that the increase in TBF was solely as a result of increased skin blood flow. This assumption was also implemented in a study by Wyss et al. (1975) investigating skin blood flow responses to elevated skin and core temperatures at rest. Venous occlusion plethysmography (VOP) was used here as an indicator of TBF while the participants were resting and passively heated. The results showed clear increases in TBF as a function of increasing core temperature, which, working on the aforementioned assumption of the contribution of skin blood flow to TBF, indicates a significant relationship between core temperature changes and forearm skin blood flow.

### 2.1.iv Sweating Responses

The sweating response is a function of the combination of core and skin temperature increases (Libert et al., 1982; Wyss et al, 1974), however it has been noted that responses are highly individualised (Libert et al., 1982; Bates and Miller, 2008). A lower sweating threshold, where sweating can be induced by much smaller increases in body temperature, is often associated with higher training status (Green et al., 2004; Ichinose et al., 2009) or acclimatisation to a hot environment (Nadel, 1979). Such adaptations provide a much quicker thermoregulatory response and can improve endurance performance in the heat due to more effective heat dissipation (Nielsen et al., 1993; Nielsen 1994; Nielsen, 1998).

Yoshida et al. (1995) observed a sweat loss of 56.53 $ml \cdot kg^{-1}$ body mass following 5 hours of baseball at a relatively high ambient temperature of 36.7°C. This calculates at 0.2 $ml \cdot kg^{-1} \cdot min^{-1}$. Amorim et al. (2006) observed sweat rates of 4.4 $l \cdot hr^{-1}$ following 120 minutes of cycling at an oxygen uptake of 1.65 $l \cdot min^{-1}$. In comparison, Lee et al. (2002) demonstrated resting sweat rates of ~1.2 $l \cdot hr^{-1}$, which were then elevated to ~5.8 $l \cdot hr^{-1}$ and 11.8 $l \cdot hr^{-1}$ following 20 minutes of cycling at 40% and 65% $\dot{V}O_{2pk}$ respectively. This study also noted a significantly delayed onset of sweating following 16 days bed rest, i.e. detraining. Therefore this supports results where a higher training status can elicit an earlier onset of sweating and therefore more effective thermoregulatory control.

## 2.2 Upper Body vs. Lower Body Exercise

When comparing upper and lower body exercise it is important to consider two elements. First there are the differing physiological factors, such as greater heat storage and vascular fluid shifts, which have been noted due to smaller muscle mass and relatively less efficient cardiovascular responses (Sawka et al., 1984; Pimental et al., 1984; Sawka, 1989). Secondly, it is important to examine the differences in thermal responses that occur as a result of these physiological differences and the adaptations that are required to address them.

Pimental et al. (1984) observed a variety of different responses between lower and upper body exercise when comparing absolute and relative exercise intensities. Firstly, in the absolute intensity experiments ( $\dot{V}O_2$ 1.6 $l \cdot min^{-1}$) heart rates were observed to be significantly greater with arm cranking than with cycling after 30 minutes of exercise. In addition, minute ventilation (VE) was observed to be significantly greater with arm cranking than with cycling throughout the whole experiment. Plasma volume decreased significantly more with arm cranking (-9%) than with cycling (-4%) and blood lactate levels were significantly greater after 20 minutes of exercise. This is all indicative of exercising at a greater % of exercise capacity. Indeed, an intensity of 1.6 $l \cdot min^{-1}$ represents 44% and 62% of peak oxygen uptake for cycling and arm cranking trials respectively. In the relative intensity trials (60% $\dot{V}O_{2pk}$) a significantly lower average heart rate for arm cranking (129 $b \cdot min^{-1}$) was observed compared to cycling (156 $b \cdot min^{-1}$) and heart rate was significantly lower (>20 $b \cdot min^{-1}$) at all time points for arm cranking. VE was reported to be significantly higher for arm cranking (36 $l \cdot min^{-1}$) than cycling (33 $l \cdot min^{-1}$) throughout the relative intensity trials. No differences were observed for either lactate or plasma volume in the relative intensity trials. This study demonstrates the physiological differences between continuous upper body and lower body exercise. Additional work by (Sawka et al., 1984) provides clear indications of the different demands of upper body exercise and demonstrate the need for further study into upper body exercise.

A number of factors are thought to cause differing thermoregulatory responses during upper body and lower body exercise. The much smaller muscle mass of the arms compared to the legs results in a greater metabolic rate and heat production for a given power output (Sawka, 1984; Sawka et al., 1989). This will, in turn, result in a greater requirement for heat dissipation from the arms. As a result of this the hypothalamus will increase stimulation of sweat glands and increase vasodilation in the peripheral arterioles leading to greater sweat rates and skin blood flow (Pendergast, 1989). However the smaller surface area to mass ratio of the arms does provide a greater potential for heat loss (Sawka et al, 1984). Another factor in the differing thermoregulatory responses during upper and lower body exercise could be the differences in catecholamine production, which has been observed to be greater during exercise with a smaller muscle mass (Davies et al., 1974). This would result in a greater heart rate and blood pressure during upper body exercise compared to lower body exercise. This is likely due to a greater stress response whilst exercising a smaller muscle mass at the same absolute power output as a larger muscle mass (Sawka et al., 1984; Harrison, 1985). Therefore during upper body exercise concentrations of adrenaline and noradrenaline are likely to increase, resulting in a larger vasoconstrictor drive to the non-exercising areas (Sawka, 1989). This is supported by the association of upper body exercise with a larger total peripheral resistance (TPR) in the peripheral circulation, which can occur as a result of increased concentrations of adrenaline and noradrenaline (Fahs et al., 2009). A greater TPR will lead to a reduction in blood flow and an increase in blood pressure during upper body exercise compared with lower body exercise at a given exercise intensity (Toner et al., 1983; Toner et al., 1990).

Decreased plasma volume has been associated with impaired thermoregulatory responses during lower body exercise in the heat (Sawka, 1984). A significantly larger haemoconcentration has been observed during upper body exercise compared with lower body exercise, indicating a greater decrease in plasma volume (Miles et al., 1983; Pimental et al., 1984). Therefore the thermoregulation response is likely to be less efficient during upper body exercise due to less efficient blood flow to the skin caused by increased blood viscosity. This will then impair the ability to lose heat via the peripheral circulation. Sweat rates and evaporative cooling may also be impaired due to the association of decreases in plasma volume and dehydration (Sanders et al., 2001).

### 2.2.i Thermoregulatory Responses

Sawka et al. (1984) examined the thermoregulatory responses to upper body exercise in comparison to lower body exercise at relative and absolute workloads. For the absolute intensity experiments the participants were required to arm crank or cycle at a power output eliciting an oxygen uptake of 1.6 $l \cdot min^{-1}$. The relative intensity experiments required 60 minutes of arm cranking or cycling at 60% $\dot{V}O_{2pk}$. During the absolute intensity trials, mean skin temperatures were found to be lower for arm cranking than cycling whilst there were no significant differences between the two modes of exercise for rectal temperature. Conversely, during the relative intensity trials rectal temperatures were significantly lower for arm cranking than cycling, as were sweat losses. The authors suggested that it was not the size of the active muscle mass that affected thermoregulatory responses to exercise but that responses were dependent upon the absolute metabolic intensity of the working muscle mass. During the relative intensity upper body trial calf skin temperature was shown to be significantly lower. This is likely due to the redistribution of blood from the lower body that is often observed during upper body exercise (Price and Campbell, 1997; Price and Campbell, 2002). As the other skin temperature measurements showed no significant change, the decrease in calf skin temperature would have a significant effect on the calculation of mean skin temperatures. These results demonstrate the marked difference between upper and lower body exercise and the unique responses associated with upper body exercise in a temperate environment.

Another difference between upper and lower body exercise could be the venous return. One major mechanism involved in venous return is the effect of the skeletal muscle pump where exercising muscles exert pressure on local veins and venules and force the blood along. When seated and performing upper body exercise there is very little contracting of lower body muscles and as such a significantly reduced effect of the skeletal muscle pump. Indeed it has been observed that incorporation of lower body movement into upper body exercise results in reduced heart rate with an elevated $\dot{V}O_2$ (Toner et al., 1983). If venous return is compromised then stroke volume will be decreased and relative heart rate will increase resulting in a much lower cardiac output (Miles et al., 1984; Sawka, 1984; Toner et al., 1983). There is, however, evidence to suggest sympathetic nervous system activity in the calf during may compensate for the absence of muscle pump activity during upper body exercise (Hopman et al., 1993). This is likely in order to prevent blood pooling in the inactive lower body.

Studies investigating thermoregulatory responses to upper body exercise have often focussed on participants with paraplegia (Muraki et al., 1995; Theisen et al., 2001; Price and Campbell, 1997) in comparison to able-bodied controls. Muraki et al. (1995) investigated the skin blood flow responses of the lower body, primarily the thigh, during arm cranking exercise. Results from the able-bodied controls displayed a significant gradual increase in thigh skin blood flow during incremental exercise, indicating an active vasodilator effect in the lower body. This demonstrates the importance of heat dissipation over the whole body surface during upper body exercise and the essential role played by the local microvasculature in adapting to thermoregulatory responses.

The importance of the sympathetic nervous system in thermoregulatory responses is highlighted by Theisen et al. (2001). This study observed that after exercise at 50% of individual maximal power output for 60 minutes esophageal temperature in able-bodied controls rose 0.5 ± 0.2°C along with a 1.99 ± 0.52°C decrease in skin temperature. The data for the two spinal cord injury (SCI) groups demonstrated a significantly greater increase in esophageal temperature (0.8 ± 0.4°C and 0.9 ± 0.1°C) along with very little change in skin temperature (0.2 ± 0.2°C and 0.4 ± 0.9°C). This indicates that the impairment of sympathetic neural responses to exercise in the SCI groups results in less efficient thermoregulation, greater core temperature, and therefore a smaller exercise capacity.

Price and Campbell (2002) examined the thermoregulatory responses of able-bodied, upper body trained participants to prolonged upper body exercise. In this study participants performed arm crank exercise for 60 minutes at 60% $\dot{V}O_{2pk}$ in two different ambient temperatures (21.5 and 31.5°C). Significant increases were seen in both conditions for aural temperature (0.7 ± 0.7°C and 1.6 ± 0.7°C for cool and warm conditions respectively) with a continuous increase reported during exercise in the warmer conditions. Upper body skin temperatures were also seen to significantly increase in the same fashion. Lower body skin temperature responses also differed between the two conditions. During exercise in the cool calf skin temperatures were seen to decrease, whilst during exercise in the heat they were seen to significantly increase. During upper body exercise in cool conditions there is likely to have been a decrease in blood flow to the lower body (Price and Campbell, 1997; Theisen et al., 2001) as there is little active muscle mass in the area. Therefore skin temperature would decrease due to receiving less blood from the core and the lack of direct vascular conductance from the calf muscle itself.

During upper body exercise in warm conditions the lower body has been considered to be a site for heat storage (Sawka et al., 1984; Price and Campbell, 2002). In order to achieve significant heat dissipation from the lower body during upper body exercise in the heat there would have to be active cutaneous vasodilation in the lower body allowing greater blood flow and therefore restricting the usual redistribution of blood to the more active muscles of the upper body. Therefore during exercise in warmer conditions the blood flow to the active muscles may be compromised by the need to increase heat loss from inactive areas.

## 2.3 Exercise In the Heat

The combination of the physiological responses to exercise and the impairment of heat dissipation mechanisms due to high environmental temperatures leads to a “major physiological challenge”, which manifests itself in various forms (Hargreaves, 2008). This elicits an even greater need to attenuate exercise-induced hyperthermic responses than exercise in moderate climates. Along with the physiological strain of exercise in the heat there are also metabolic changes that contribute to fatigue. Exercise in the heat has been shown to affect the energy source used with fat metabolism decreasing and muscle glycogen being used as the primary fuel source (Febbraio et al., 1994). If this is the case then muscle glycogen stores will be degraded much more quickly during exercise in the heat leading to earlier fatigue. In order to attenuate this effect an athlete may be required to take on extra carbohydrates during and/or before exercise in a hot environment to compensate for this inevitable increased degradation of energy stores. The hyperthermic effects of exercise in the heat are also greatly detrimental to cardiovascular function, decreasing stroke volume and cardiac output, and therefore limiting oxygen delivery and maximal oxygen uptake (Gonzalez-Alonso and Calbet, 2003). When maximal oxygen uptake is combined with the decrease in muscle blood flow exercise capacity is greatly compromised. This is further accentuated by dehydration (Hargreaves, 2008), emphasising the importance of continuous rehydration during exercise to maintain muscle blood flow and adequate oxygen delivery to the working muscles.

Another fatiguing effect of exercise in the heat is its contribution to central fatigue and decreased muscle activation (Nybo and Nielsen, 2001). Decreased activation of muscles will lead to less force production and therefore a decrease in exercise performance. Whilst these effects, whether physiological, metabolic or neural, can be attenuated via various means during exercise, if it is possible to directly diminish the effects of the heat upon the body this will be infinitely beneficial to exercise performance. In order to achieve this there have been a number of investigations into the use of cooling techniques as a method of improving heat dissipation.

## 2.4 Cooling Techniques

In order to attenuate the increases in core and skin temperatures associated with combined exercise and heat stress, a variety of active cooling strategies can be used (e.g. Whole-body cooling, partial body cooling, hand and foot cooling). Whole-body cooling prior to exercise is intended to decrease body temperature. This therefore increases the ability of the body to store heat (Marino, 2002). Partial body cooling may take the form of specially designed clothing, for example a cooling vest, or may involve the application of ice packs on designated areas of the body. These methods can be used during exercise and aim to attenuate the increases in core temperature caused by increases in metabolic heat production. Cooling via the hands and feet can also be used during exercise with the application of water-perfused gloves or socks. In addition, hand and foot cooling can be used post-exercise or during a rest period, in order to increase heat dissipation.

### 2.4.i Whole-body Cooling

One method demonstrated by Drust et al. (2000) is whole-body cooling, which involves cooling the entire body surface with cool water prior to exercise. This study examined the effects of a 60 minute cool shower (26°C) on a 90 minute intermittent treadmill exercise. This protocol was performed at a room temperature of 20°C and also in a heated environment at 26°C. Rectal temperature was observed to be significantly decreased after pre-exercise cooling compared to no cooling (-0.6°C). However there were no significant differences observed in physiological responses to exercise between pre-cooling and no cooling trials at room temperature. Post exercise rectal temperature was observed to be significantly lower in the temperate environment following pre-cooling (38.1 ± 0.6°C) than in the heated environment with no pre-cooling (38.6 ± 0.3°C). This indicates that the effects of pre-cooling are much more beneficial when performing in a warmer environment. This demonstrates a great benefit of whole body cooling in that beginning exercise at a lower core temperature will increase the time taken to reach critical core temperature and exhaustion. Whilst the difference in environmental temperature may well have contributed to the greater rectal temperature values in the heated trials, it should be noted that the difference in ambient temperature was relatively small (6°C). It is, therefore, encouraging to note the effects of pre-cooling in attenuating core temperature increases observed in this study as this could play a major role in prolonging intermittent exercise performance in the heat.

White et al. (2003) also investigated whole-body cooling prior to exercise. In this study participants were submerged up to the neck in water at 20°C prior to exercise. Pre-cooling was shown to be effective in attenuating core temperature increases during exercise but is impractical for most real life situations and is often reported to be quite uncomfortable by participants. White et al. (2003) also compared the effects of whole body and lower body immersion pre-cooling techniques on physiological responses to exercise in the heat. This study involved the participants undergoing a pre-cooling period of either whole body or lower body immersion for 30 minutes prior to cycling at 60% $\dot{V}O_{2max}$ in an ambient temperature of 30°C for 30 minutes. Significant thermoregulatory differences were observed between the two cooling methods. Rectal temperature was found to decrease significantly more during whole body immersion compared with lower body immersion alone. Furthermore rectal temperature remained significantly lower for 24 minutes into the subsequent exercise period following whole body cooling. Mean skin and body temperatures were also found to be lower after whole body immersion. However these responses only remained decreased for 14 minutes into exercise as core temperature began to rise. Thermal comfort and thermal sensation ratings measured in this study showed that whole body immersion provides lower overall ratings when compared to lower body immersion due to more of the body being covered by water, resulting in a greater amount of thermal exposure. Indeed during whole body immersion rectal temperature significantly decreased from baseline after 24 minutes, whereas there was no significant decrease observed for lower body immersion. This study also noted that sweat sensation ratings were significantly lower after whole body immersion than after lower body immersion for up to

20 minutes into exercise, indicating a greater decrease in thermal strain after whole body cooling.

### 2.4ii Ice Vests

Upper body cooling is often employed, using a water-perfused suit or ice vest, by athletes participating in both upper body dominated activities (rowing/kayaking) and lower body dominated activities (Duffield et al., 2003). Ice vests can be used prior to exercise, in the same manner as whole-body cooling, in order to decrease body temperature and increase heat storage capacity. Lightweight ice vests can also be used during performance as a means of counteracting rises in core temperature. Whilst ice vests are effective in reducing the physiological and metabolic effects of exercise, they are not always shown to significantly improve subsequent exercise performance (Cheung and Robinson, 2004). In particular, it is noted that cooling methods in general have inconsistent effects on short duration, higher intensity exercise performance when compared to longer duration endurance performance (Marino, 2002).

It has been hypothesised that the benefit of pre cooling on performance is that athletes are able to perform for a longer duration and increase intensity late on in an event due to a greater offset of their critical core temperature (Booth et al., 1997; Kay et al., 1999). This would explain the lack of improvement noted in short duration, high intensity exercise following pre cooling as the athletes are already exercising at a relatively high intensity and as such a further increase is more difficult to achieve. This could also indicate that the limiting factor in shorter duration, high intensity exercise may not be thermal. Indeed it has been noted that intermittent sprinting performance is mainly limited by an inability to supply sufficient energy (creatine phosphate) to the working muscle and the accumulation of lactate (Glaister, 2005). Duffield et al. (2009) observed significant improvements in 30 minute intermittent sprint performance of lacrosse athletes after pre-cooling with a combination of ice vests, and cold towels on the neck and ice packs on the quadriceps. The athletes covered a significantly greater distance in the pre-cooling trial (3.35km) compared to control (3.11km) and a significant attenuation of core temperature (mean difference of 0.5°C).

Price and Mather (2004) investigated the effects of upper and lower body cooling during upper body exercise. Participants were required to perform arm cranking exercise at 50% $\dot{V}O_{2pk}$ for 30 minutes with ice packs over the abdomen, back and chest for upper body cooling and over the hamstrings, thigh and calf muscles for lower body cooling. The results of this study showed a significant attenuation of the rectal temperature increase during lower body cooling when compared with upper body cooling and control trials. In addition, both cooling methods resulted in a significant attenuation of aural temperature increases when compared with the control trial. Significant decreases in mean skin temperature were also noted in both cooling trials at the onset of exercise, remaining at lower levels throughout the exercise period.

Hunter et al. (2006) employed ice vests to cool cross country athletes one hour prior to 4km and 6km races. They observed significantly lower core temperatures in the cooling group directly prior to (no vest: ~38.25°C, with vest: ~37.75°C) and directly following (no vest: ~40°C, with vest: ~39.5°C) the races. Despite the differences in core temperature there were no significant differences in performance times recorded for either the 4km (no vest: 15:01 ± 0:30, with vest: 14:58 ± 0:13) or the 6km (no vest: 18:27 ± 0:56, with vest: 18:15 ± 0:42) races. It is difficult to assess the effects on performance from this study as the athletes used in the experimental group were not the same as those used in the control group making it difficult to compare results between the two.

Webster et al. (2005) examined cooling using ice vests during a 30 minute run at 70% $\dot{V}O_{2max}$, followed by a performance trial at 95%$\dot{V}O_{2max}$. Three different cooling trials with different cooling vests and a no cooling control were undertaken. The cooling vests were worn at rest and during warm up but not during the exercise periods. One of the vests did result in a significantly improved endurance performance time (164.6 s) when compared to control (115.3 s) as it was a more close-fitting, shorter vest than the others made from a relatively impermeable fabric. A closer fitting vest will allow for greater contact with the skin surface and as such may improve the transfer of heat from the skin and an improved ability to maintain a cooler body temperature. Despite the improvements in performance time with the one vest, core temperatures were not shown to be significantly different between the trials following the warm-up or at any point during exercise. However, core temperature was seen to rise less in the three cooling trials than in the control trial. The improvement in performance with the one vest design demonstrates that benefits may be gained for endurance performance from certain types of cooling vests. However, these studies all observe the effects of cooling on running performance and there is little indication as to the possible specific benefits for upper body exercise.

Webborn et al. (2005) investigated the effects of pre-cooling with an ice vest on intermittent sprint performance of tetraplegic participants. This study involved three trials, each beginning with 20 minutes of rest prior to a warm up followed 14 exercise bouts of two minutes. The two minutes of exercise consisted of 10 seconds passive rest followed by a five second maximal sprint and 105 seconds at 35% $\dot{V}O_{2pk}$. One trial involved the participants wearing an ice vest for the 20 minutes prior to exercise but removing it before participating in the exercise protocol (Pre). The other intervention trial involved wearing the ice vest during the warm up and exercise periods but not at rest (Dur). The third trial was a control trial involving no cooling intervention at any point (Con). Core and skin temperatures were shown to be significantly decreased ($0.3 \pm 0.1$°C and $1.7 \pm 0.4$°C respectively) during the resting period of Pre but not during Dur or Con. Mean skin temperature was also observed to be significantly lower for both Pre ($1.7 \pm 0.3$°C) and Dur ($1.5 \pm 0.2$°C) than for Con ($2.5 \pm 0.2$°C) after five minutes of the warm up phase. Mean skin temperature then remained lower during Pre and Dur than Con throughout the remainder of the warm up phase. However, there were no significant differences observed for power output during exercise between the three trials. In contrast, Webborn et al. (2010) demonstrated a significant improvement in upper body intermittent sprint performance in the heat in tetraplegic athletes following cooling. Cooling strategies prior to and during exercise were both observed to result in significant improvements in time to exhaustion and number of sprints performed compared to the control trial. These results further demonstrate that whilst ice vests can provide a significant reduction in core and skin temperature, there is still contrasting evidence as to the effects on subsequent intermittent sprint performance.

### 2.4.iii Cooling Suits

Water-cooled and air-cooled vests are two forms of body cooling often used in laboratory settings. These suits involve cold water or air being passed through tubing within the clothing, creating a cooler environment around the body and allowing for convective heat loss to the circulating water or air. The respective advantages and disadvantages of these types of cooling were compared in a study by Shapiro et al. (1982) in hot-dry and hot-wet environments. The results of the study showed that in the hot-wet environment both air and water-cooled vests significantly attenuated increases in core and skin temperature when compared to the ambient air trial. Furthermore, heat storage was significantly lower with both the air and water cooled suits compared to the ambient air trial. Heat storage, and both skin and core temperature results showed no significant differences between the air and water-cooled suits, however heart rate was shown to remain significantly lower with the air-cooled vest than the water-cooled. This could be due to a difference in weight between the suits as the water circulating the water-cooled suit would be heavier then the air in the air-cooled suits.

Data from participants wearing a water-cooled suit at rest for two hours in 30, 35 and 40°C has demonstrated significant benefits in alleviating heat strain (Nag et al., 1998). Whilst there were no significant differences demonstrated between resting with and without the suit at 30°C, skin and core temperatures were maintained at a significantly lower level during the 35 and 40°C trials (core = 36.7 ± 0.2°C and 37.5 ± 0.2 °C respectively) with the suit compared to without. However, Barwood et al. (2009) demonstrated an air-cooled garment to be more effective than a liquid cooled garment at extracting heat at a core temperature of 38.5°C following treadmill exercise. The air-cooled garment was observed to facilitate heat loss of 101W over a 30 minute cooling period whereas the liquid-cooled garment facilitated 49W. It is apparent that the relative efficacy of liquid and air-cooled clothing for heat loss may differ based on the material, the mode of exercise and the area of the body covered by the garment. However, no performance trial was undertaken in this study to determine whether subsequent exercise performance was improved.

### 2.4.iv Hand Cooling

Cooling via the hands and feet is a particularly effective cooling method post exercise (or at high core temperatures) due to the greater capillarisation in these areas compared with the other areas of the body (Rowell, 1983; House, 1997). The greater concentration of capillaries results in a significantly larger blood volume where the tissue is vasodilated. Therefore, when the blood temperature is elevated as a result of elevated core temperature there will be a larger temperature gradient between the cutaneous blood and the water used for cooling to allow for heat dissipation. The increased blood volume in the hands and feet following vasodilation also means that a greater volume of blood can be cooled resulting in rapid cooling. This increase in cutaneous blood volume will all occur as a function of an elevated core temperature, which increases the drive for heat loss with an increased cutaneous blood flow. Cooling will therefore be much more effective at higher core temperatures as the warmer blood flowing through the hypothalamus will increase stimulation of the hypothalamus and increase efferent output to the peripheral circulation. Consequently vasodilation will be increased in the peripheral circulation and a greater blood flow will occur, allowing for a greater volume of blood to be cooled. Furthermore, the extremities offer a far more practical area for cooling as they are easily accessible and rarely heavily covered.

The effectiveness of hand and foot cooling is dependent on the peripheral blood flow in the extremities (House, 1997). If extremity peripheral blood flow is reduced then the transportation of cooled blood back to the core will be much slower, therefore the blood will have more time to regain heat during transit and the cooling effect at the core will be significantly reduced. Therefore when the hands are placed in cool water it is necessary for the heightened peripheral blood flow from exercise to be maintained so that effective cooling at the core can occur. This is possible due the presence of interconnecting vessels called arteriovenous anastomoses (AVAs). AVAs directly connect small arteries and veins in the extremities and therefore bypass the capillary bed. It has been reported that core temperature appears to be the major contributor to the control of these vessels (Johnson and Park, 1979) and as such they are can act independent of skin temperature. Therefore, with an elevated core temperature, AVAs will remain dilated even when the skin temperature of the extremities is greatly reduced. This allows peripheral blood flow to be maintained in the extremities when the hands or feet are placed in cool water, resulting in much more efficient transport of cooled blood from the extremities to the core and a greater cooling effect (House, 1997).

Cooling via the hands was investigated by Livingstone et al. (1989) with participants performing treadmill walking whilst wearing heavy protective clothing. The protocol involved 20 minutes of exercise at two intensities, each followed by a 20 minute resting period with hands immersed in water at 5 different temperatures (10, 15, 20, 25, and 30°C). The results showed that colder water produced more effective heat dissipation from the hands. Furthermore they demonstrate the heavier the initial workload the more effective the cooling. During the higher intensity exercise skin blood flow would have increased due to greater vasodilation of the peripheral circulation, resulting in a larger volume of blood passing through the skin microcirculation and greater heat loss potential. The heavier workload may also have resulted in more effective cooling due to the greater metabolic heat production inducing a greater core temperature than the lighter workload. This would further increase the skin blood flow and therefore increase the cooling gradient allowing for quicker and more aggressive heat dissipation.

Similar results were later found by House et al. (1997) who examined the effectiveness of cooling post exercise in the heat via immersing the hands in water at three different temperatures (10, 20 and 30°C). The participants were clothed in a Royal Naval fire fighter ensemble at 40°C. Participants then rested for 30 minutes in the same conditions where cooling was applied. The results from this study showed hand cooling to significantly decrease aural temperature at all three water temperatures when compared with the control. Cooling was shown to be more effective and to occur more aggressively at the lowest water temperature (10°C). It was noted in this study that the cooling gradient between the hands and the water was greatest up to 18 minutes into the cooling process in the three cooling trials, which is when the majority of the heat loss occurred. The studies by Livingstone et al. (1989) and House (1997) are both good examples of the effectiveness and benefit of cooling via the hands. Although the studies were not designed to measure performance they demonstrate a significant decrease in core and mean skin temperatures that could be vital to prolonging exercise performance in a physiologically stressful environment and preventing the development of heat induced illness. Moreover, considering both protocols involved the use of heavy protective clothing that significantly impedes evaporative cooling, they give an insight into how extremity cooling can be used by individuals involved in operations requiring protective clothing.

The effects of hand cooling on endurance performance have also been examined in paraplegic (PA) and able-bodied athletes (AB) (Goosey-Tolfrey et al., 2008). Participants performed an intermittent cycling (AB) or wheelchair ergometry (PA) protocol, consisting of 5 x 10 minute bouts, for 60 minutes at 30.8°C, before a 10 minute resting period where the cooling intervention was administered. The participant's hands were immersed to the wrists in water at 10°C for the cooling intervention, whilst for the control trial the participants simply remained resting with no intervention protocol. Following cooling or control an endurance performance trial of 3km cycling for the AB group and 1km wheelchair ergometry for the PA group was undertaken. The results from this study show firstly that the AB group showed greater decreases in aural temperature during cooling than the PA group. This could indeed be due to the greater aural temperature values observed in the AB group (38.5°C) compared to the PA group (37.5°C) prior to cooling. It should be noted however that, due to the differences in exercise activity being performed, it is difficult to accurately compare results between the two groups in this way. Whilst the AB group performed a cycling protocol using mainly lower body exertion, the PA group would have been solely using upper body exertion for wheelchair ergometry. Endurance performances were shown to have improved in both groups (5.0% and 4.6% for AB and PA, respectively) however only the AB group showed a significant improvement. This study also noted that the training status of all the athletes used was not controlled, which could lead to the cooling method being more effective for some participants than for others. Higher training status is associated with improved cutaneous blood flow (Volianitis and Secher, 2002; Volianitis et al., 2004; Koch et al., 2005) and this will enable a greater circulation of cooled blood and hence improve the dissipation of heat during hand cooling. The relationships between groups may also have proved stronger had each athlete covered the same, or at least similar, distance in the performance trial.

Hsu et al. (2005) demonstrated an improvement in 30km cycling time trial performance in 31.9°C conditions in able-bodied subjects after hand cooling when compared with no cooling. In this study all of the subjects performed the same time trial distance although the much greater length of this time trial gives a larger margin for time fluctuations within subjects. Both these studies, however, indicate a strong relationship between hand cooling and improved endurance cycling performance but as yet there have been very few studies investigating upper body endurance performance.

### 2.4.v Foot Cooling

Cooling via the feet was also investigated by Livingstone et al. (1995). This study involved two separate cooling experiments, one with the bare feet immersed in water and the other using water perfused cooling socks specially designed to alleviate heat strain by cooling the extremities. This study again required the participants to wear heavy protective clothing akin to that worn by Special Forces workers in the field. Five different water temperatures were tested as with the hand cooling experiment by Livingstone et al. (1989), however there was no exercise element to the protocol for experiment one. Participants in this experiment were required to rest seated for two hours in an environmental chamber maintained at a temperature of 35°C and subsequently immerse their feet in a water bath at one of the five temperatures for 20 minutes. The results from experiment one show similar results to those found from hand cooling (Livingstone et al., 1989; House et al., 1997) in that more heat was dissipated using the cooler water temperatures.

The second experiment by Livingstone et al. (1989) involved 60 minutes of rest followed by 90 minutes of treadmill walking during which the feet were cooled using the cooling socks. Four trials were performed, in which the feet were cooled for either: the entire exercise period; the last 60 minutes of exercise; the first 30 minutes of exercise; or not cooled at all. The results from this experiment demonstrate, as with hand cooling, that the greater the core temperature the greater the heat dissipation during cooling. It is also shown here that cooling was more effective in attenuating core temperature increases in the latter stages of exercise when compared to the early stages. This could be due to the greater core temperature during the latter stages of exercise, which would provide a greater drive for heat loss and therefore more effective cooling.

Hagobian et al. (2004) demonstrated foot cooling to lower tympanic temperature in SCI participants during exercise in the heat. Participants performed 45 minutes of arm crank exercise at 66% $VO_{2pk}$ in 31.8 ± 0.2°C heat, followed by 30 minutes of recovery with either foot cooling or no cooling. This study demonstrated a significantly lower tympanic temperature during recovery with foot cooling (1.0 ± 0.2°C) than with no cooling (1.6 ± 0.2°C). These results strengthen the case that foot cooling could be used as a significant method of heat extraction in spinal cord injured populations exercising in the heat. In addition, this effect of foot cooling could be accentuated when considering the heat storage that has been shown to occur in the lower body during exercise in the heat (Price and Campbell, 2002).

Along with attenuating core temperature increases cooling the feet also decreased mean skin temperature, which did not include foot skin temperature. When cooling ceased mean skin temperature was shown to rise again. This study further supports the results found in hand cooling studies in that cooling using the extremities can alleviate the physiological strain of exercise and heat stress. Foot cooling may be further beneficial in that the hands can remain warm and therefore manual dexterity will be maintained. This could be beneficial to sports or other activities where manual dexterity is necessary in the hands to perform key tasks. It could be particularly beneficial in sports where athletes are required to wear a great deal of protective clothing and where matches often take place in hot climates as these athletes are the most vulnerable to hyperthermia and dehydration. If the structure of the game allows it then extremity cooling could be applied effectively in a 10-15 minute break.

## 2.5 Summary

This literature review has focussed on the key elements of thermoregulation during upper body exercise in the heat and cooling techniques previously used to alleviate thermal strain. As noted previously, upper body exercise is an important area of study primarily due to the differing thermal responses compared with lower body exercise (Sawka, 1984; Pimental et al., 1984; Sawka et al., 1989). The understanding of these differences is vital in the battle to alleviate heat strain for those involved in exercise with a large upper body component. The various cooling techniques have shown that thermal responses can be manipulated by manually cooling the body prior to (Drust et al., 2000; White et al., 2003) or during exercise (Livingstone et al., 1989; 1995). It has also been observed that cooling techniques can significantly improve exercise performance (Hsu et al., 2005; Goosey-Tolfrey et al., 2008). The beneficial effects of hand and foot cooling previously observed are encouraging as these methods are much more practical than the others discussed and their implementation requires very little specialised equipment or techniques. However, the effects of hand and foot cooling have, so far, only been assessed for lower body exercise or wheelchair based performance. Therefore, little data is available concerning the effects of hand and foot cooling on arm crank ergometry performance.

To the author's knowledge, no study has yet reported the effects of hand and foot cooling on arm cranking exercise performance in a hot environment. The current study aims to assess and compare the effects of hand and foot cooling on the physiological and thermoregulatory responses to upper body exercise in the heat. As has been previously mentioned, studies examining extremity cooling have thus far mainly focussed on lower body exercise. The unique physiological responses associated with upper body exercise such as greater heat storage and catecholamine release require that further investigation is performed into this area in order to determine the specific benefits to those performing such exercise in everyday situations such as wheelchair users. Such information could prove useful and vital to various populations both in and outside of sport. Athletes who could benefit from the knowledge of the most effective cooling methods include most who participate in team sports with significant (>10mins) intervals where cooling could be applied. Such sports as rugby and American football are prime examples of those requiring a large component of upper body exercise, which is necessary to be sustained at a high level throughout the entirety of a match situation. Outside of sport beneficiaries may include those working in operations such as bomb disposal or fire fighting where a great deal of protective clothing has to be worn, resulting in extremely difficult exercising conditions. Foot cooling again may be particularly helpful to these populations as it would eliminate the loss of dexterity in the hands that may be observed from cooling the hands directly. Many military operations now take place in extreme climates where dehydration and hyperthermia are a real threat to exercise performance. However, although more practical than whole-body cooling, there are still issues with the methods extremity cooling as described in this review. If these cooling methods could be somehow adapted and utilised prior to, between, or during operations then they would provide a significant aid in attenuating such effects and could vitally improve exercise performance.

## 2.6 Aims and Hypotheses

This study aims to examine the effects of hand and foot cooling on thermoregulatory responses and upper body exercise performance in the heat. From the previous literature

(Livingstone et al., 1989; 1995; House et al., 1997) it is expected that hand and foot cooling will both result in a significantly greater heat loss from the extremities during cooling than the control trial. Considering the results of Goosey Tolfrey et al. (2008) and Hsu et al. (2005) it can be hypothesised that the hand cooling intervention may result in a significant improvement in endurance performance compared to the control trial. However it is not possible to hypothesise any comparative effects between hand and foot cooling as the authors are not aware of any previous study that has compared these two methods.

# 3.0 Methods

Seven healthy male participants (age 25.9 ± 7.3yrs; height 177.0 ± 6.8cm; weight 83.7 ± 20.3kg) from the University population volunteered for this study. All participants attended an introductory session in which they were fully informed of all procedures and equipment to be used. Study information was provided both verbally and via an information sheet outlining the protocol of the study, equipment to be used and what was required of them as participants. All participants gave their written consent to participate in the trials. All were required to fill out a general health questionnaire prior to each session to ensure they had no health problems or illnesses that would be affected by participation in the study. Furthermore, participants were asked whether they had undergone any previous heat acclimation procedures. The study was approved by the University Ethics Committee (Appendix A).

## 3.1 Preliminary Trial

Participants reported to the laboratory on four separate occasions. The first visit involved a maximal incremental arm cranking test to determine peak oxygen uptake ($\dot{V}O_{2pk}$) and peak power ($W_{pk}$) using an electronically braked arm crank ergometer (Lode Angio, Groningen, Netherlands). A ramp protocol was used which involved two minutes of arm cranking at 50 W followed by an increase of 1 W every 6 s (Smith et al., 2007). Participants were asked to maintain a cadence of 70 rev·min$^{-1}$ until volitional exhaustion, taken as the point at which participants voluntarily ceased exercise or their cadence fell below 65 rev·min$^{-1}$ for more than ten seconds. An online breath-by-breath analysis system (Cosmed K4b$^2$, Cosmed, Rome, Italy) was used to analyse expired gas for oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation (VE), and respiratory exchange ratio (RER) throughout the test. Ratings of perceived exertion (RPE) were assessed for the arms and whole body using the Borg scale (Borg, 1970). Heart rate was continuously monitored using a Polar heart rate monitor and chest strap with values taken every two minutes. Capillary blood samples (70 µl) were taken at rest and at the end of the test using an automatic lancet (Softclix, Roche Diagnostics Ltd, Lewes, East Sussex, UK) for the analysis of blood lactate concentration (BLa) (Biosen C-line, Magdeberg, Germany).

### 3.2 Experimental Trials

Each subsequent visit involved arm crank exercise in the heat with either hand cooling (HC), foot cooling (FC) or a non cooling control (NC). On arrival at the laboratory participants were asked to empty their bladder after which their height and body mass were measured using a stadiometer and weighing scales (Seca, Cranlea & Company, Bourneville, Birmingham, UK). Participants then sat and rested whilst the equipment was attached. The sequence and frequency of measurements is represented in the schematic diagram in Fig. 3.1. Prior to exercise, resting baseline measurements were taken in the cool and the heat. Each testing session required the participant to arm crank at 60% of their $W_{pk}$ in the heat ($37.7 \pm 0.2^{o}$C, $27 \pm 2.4$% RH) for 20 minutes, or until core temperature reached

$39.5^{o}C$ or $2^{o}C$ above resting values. Participants then rested for 15 minutes undertaking one of two cooling conditions or a no cooling control condition, they then performed an exercise trial at 75% $W_{pk}$ at 70 rev·min$^{-1}$ in the same hot conditions until volitional exhaustion. Volitional exhaustion was assessed by the same criteria as for the $\dot{V}O_{2pk}$ test. For the FC trial the participant's feet were immersed in a container of water up to the top of the malleoli while the participant remained seated. For the HC trial the water container was mounted on a stool so the participants could place their hands up to the wrists and sit comfortably. Hands and feet were placed on a plastic grill rack within the container in order to enable full circulation of the water around them.

Figure 3.1. Data sheet for measurement protocol.

| | REST ( C ) | REST (H) | 5 | 10 | 15 | 20 | C5 | C10 | C15 | P |
|---|---|---|---|---|---|---|---|---|---|---|
| HR (bpm) | | | | | | | | | | |
| Chest SkT (°C) | | | | | | | | | | |
| Bicep SkT (°C) | | | | | | | | | | |
| Thigh SkT (°C) | | | | | | | | | | |
| Calf SkT (°C) | | | | | | | | | | |
| ReT (°C) | | | | | | | | | | |
| AuT (°C) | | | | | | | | | | |
| HandT (°C) | | | | | | | | | | |
| FootT (°C) | | | | | | | | | | |
| Lactate (mmol) | | | | | ---------- | | ---------- | ---------- | | |
| RPE (Arms) | ---------- | ---------- | | | | | ---------- | ---------- | ---------- | |
| RPE (Overall) | ---------- | ---------- | | | | | ---------- | ---------- | ---------- | |
| TS | ---------- | ---------- | | | | | ---------- | ---------- | ---------- | |
| SC SkBF (% inc.) | | | | | | | | | | |
| TH SkBF (% inc.) | | | | | | | | | | |
| CA SkBF (% inc.) | | | | | | | | | | |
| FH SwR ($\mu l \cdot min^{-1}$) | | | | | | | | | | |
| SC SwR ($\mu l \cdot min^{-1}$) | | | | | | | | | | |
| TH SwR ($\mu l \cdot min^{-1}$) | | | | | | | | | | |
| CA SwR ($\mu l \cdot min^{-1}$) | | | | | | | | | | |
| $VO_2$ ($ml \cdot min^{-1}$) | | | | | ---------- | | ---------- | ---------- | ---------- | |
| $VCO_2$ ($ml \cdot min^{-1}$) | | | | | ---------- | | ---------- | ---------- | ---------- | |
| VE ($l \cdot min^{-1}$) | | | | | ---------- | | ---------- | ---------- | ---------- | |
| RER | | | | | ---------- | | ---------- | ---------- | ---------- | |
| R HFlow ($W \cdot m^{-2}$) | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- | | | | ---------- |
| L HFlow ($W \cdot m^{-2}$) | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- | | | | ---------- |
| Room Temp | | | | | | | | | | |
| | | | | | | | | | | |
| Workload | | | Trial | | | | Pre w/o | Pre w/ | Post | |
| | | | | | | Water T | | ---------- | | Workload |
| Hum | | | Height | | | Total V | | | ---------- | |
| | | | | | | Water | | | | |
| Code | | | Weight | | | Ice | | | | Heat Loss (cals/s) |
| | | | | | | Hands | | | | |
| Age | | | | | | | | | | End Time |

The volume of water used was 31.5 L and was maintained as close to 10°C as possible prior to the cooling period using ice. The water was continuously stirred using a water pump (Aquaclear 3000, Rolf C Hagan Ltd, UK) to ensure a more consistent water temperature within the container and break up the boundary layer around the hands or feet. The volume of water displaced with the participant's feet or hands immersed was recorded along with the change in water temperature over the cooling period. After this period participants removed their hands or feet from the water and dried them off. Heat loss from the hands and feet to the water during cooling was calculated using the formula:

$Q = mtc\ (T_i - T_f - k)$ cals/s

Where; m = mass of water (g), t = time (s), c = specific heat capacity of water (cal/g°C), $T_i$ = temperature of water with hands immersed (°C), $T_f$ = temperature of water with hands removed (°C) and k = change in water temperature without hands immersed (°C) (Livingstone et al., 1989). Values were then converted to Watts.

Core (rectal and aural) and skin temperatures were continuously monitored throughout the protocol. Core temperature was measured by rectal and aural thermistors. Rectal temperature ($T_{re}$) was measured via a thermistor inserted 10cm beyond the anal sphincter. Aural temperature ($T_{au}$) was measured via a thermistor inserted into the ear canal and insulated with cotton wool (Kurz et al., 1993). Skin temperature was measured at six sites; the chest ($T_{ch}$) (centre of the left pectoralis major), the upper arm ($T_{arm}$) (centre of the bicep), the thigh ($T_{th}$) (centre of the rectus femoris), the lower leg ($T_{ca}$) (centre of the lateral side of the gastrocnemius), dorsal side of the hand and dorsal side of the foot. Mean skin temperature (MST) was calculated for each time point using the formula; $(0.3 \times (T_{ch} + T_{arm})) + (0.2 \times (T_{th} + T_{ca}))$ (Ramanathan, 1964). Skin and core temperatures were measured using Edale thermistors (Edale, Cambridge, UK) linked into a Grant Squirrel data logger (Grant instruments, Surrey, UK). Temperature measurements were taken every five minutes throughout the experimental period.

Skin blood flow was measured at three sites; the back (base of the right scapula), the anterior surface of the thigh and the calf (centre of the lateral side). Skin blood flow was measured using a Laser Doppler Flowmeter (Moor Instruments, Axminster, Devon, UK). Local sweat rate was measured at four sites; the forehead, the back (base of the scapula), the anterior surface of the thigh and the calf (centre of the lateral side). Local sweat rates were measured using a quantitative sweat measurement system (Q-sweat, WR Medical Electronics, Stillwater, Minnesota, USA). Measurements were assessed at five minute intervals where an average of the preceeding 30 seconds of data was taken. The traces for both skin blood flow and sweat rates were paused during transition between exercise and cooling as the participant's movement caused significant interference to recordings. During each cooling period heat flow from the hands or feet was recorded every five minutes. Heat flow disks (Data Harvest, Leighton Buzzard, Bedfordshire, UK) were placed on the dorsal side of the extremities involved in cooling. Heat flow was only measured during cooling as the disks caused significant interference during exercise, and discomfort particularly when attached to the hands.

Heart rate was measured as previously described with values recorded every five minutes. Expired gas was analysed for $\dot{V}O_2$, $\dot{V}CO_2$, VE and RER using the Cosmed K4 as previously described. However, due to an equipment malfunction resulting in the Cosmed K4 being unavailable, for a number of the final tests Douglas Bags were used to collect expired gas at rest, at 5, 15 and 20 minutes during exercise and at the end of the performance trial. Douglas bags were then analysed using a dry gas meter (Harvard

Appararus Ltd., Kent, UK). Values were obtained for $\dot{V}O_2$, $\dot{V}CO_2$, VE and RER using an in house Expair computer programme. There were no significant differences between Douglas Bag and K4 values for comparable trials. Capillary blood samples were taken as described for the

$\dot{V}O_{2pk}$ protocol at rest, 5, 10 and 20 minutes of the first exercise period and at the end of the performance trial. Ratings of Thermal Sensation (TS) (Young et al., 1987) and RPE (local and overall) were assessed at five minute intervals.

Whole body surface area (BSA) was calculated using the formula:

0.007184 x Height (cm)$^{0.725}$ x Weight (kg)$^{0.425}$ (Dubois and Dubois, 1916).

Surface area of the hands and feet was then calculated relative to whole body surface area (Dubois and Dubois, 1916) (hands = 5.04% BSA and feet = 6.6% BSA). Mass of the hands and the feet was calculated relative to body mass using values from Dempster and Gaughran (1967) (hand = 0.5% BM and foot = 1.3% of BM). The increase in water volume was recorded during cooling and from this the volume of the hands and feet was calculated. These values were then used to produce surface area to mass and surface area to volume ratios for the hands and the feet of each participant.

Participants were asked to arrive at the lab fully hydrated. Participants were asked to drink 500 ml of tap water up to 30 minutes before arrival to avoid dehydration during exercise as no water was to be consumed during each trial. Exercise induced fluid losses were calculated using changes in body mass pre and post exercise and extrapolated to $L \cdot hr^{-1}$. These values were then used to indicate the amount of fluid loss so that participants could rehydrate adequately.

## 3.3 Statistical Analysis

A two-way analysis of variance (ANOVA) with repeated measures for time and trial was used to determine differences between data sets for core and skin temperature measurements, skin blood flow, local sweat rates, expired gas variables, heart rate, RPE, TS and heat flow. Pairwise comparisons from the two-way repeated measures ANOVAs were used to analyse main effects. $T_{re}$ changes from baseline ($\Delta T_{re}$) were calculated at each time point along with $T_{au}$ and $\Delta T_{au}$. A one-way ANOVA was conducted on the results for performance time. Any significant differences found were then further analysed using Tukey's Honestly Significant Difference (HSD) analysis. A student's paired t-test was used to analyse any differences in heat loss during cooling and differences between surface area to mass and surface area to volume ratios. Correlation analysis was performed on skin blood flow and local sweat rate measurements against $T_{au}$ to determine any significant relationships between the variables. Significance was accepted at a level of $p < .05$.

# 4.0 Results

## 4.1 Peak Physiological Responses

Table 1 shows peak physiological responses and power output (PO) achieved during the $\dot{V}O_{2pk}$ test.

Table 4.1. Peak physiological responses for the $\dot{V}O_{2pk}$ test.

| Variable | |
|---|---|
| **$\dot{V}O_2$ (L•min$^{-1}$)** | 2.59 ± 0.79 |
| **$\dot{V}CO_2$ (L•min$^{-1}$)** | 2.46 ± 0.57 |
| **VE (L·min$^{-1}$)** | 86.0 ± 24.5 |
| **RER** | 0.97 ± 0.10 |
| **HR (b•min$^{-1}$)** | 181 ± 5 |
| **BLa (mmol)** | 7.0 ± 1.7 |
| **PO (W) (100%)** | 145 ± 29 |
| **PO (W) (75%)** | 108 ± 22 |
| **PO (W) (60%)** | 87 ± 18 |

## 4.2 Surface Area, Mass and Volume

Mean body, hand and foot mass, surface area and volume are presented in Table 2.

Table 4.2. Mass, surface area and volume of the body, hands and feet for the participants.

| | **Whole Body** | **Hands** | **Feet** |
|---|---|---|---|
| **Mass (kg)** | 83.7 ± 20.3 | 0.4 ± 0.1 | 1.1 ± 0.3 |
| **Surface Area (m$^2$)** | 2.0 ± 0.3 | 0.10 ± 0.0 | 0.1 ± 0.0 |
| **Volume (L)** | ---------------- | 2.1 ± 0.6 | 3.4 ± 0.7 |

A significantly larger surface area to mass ratio was observed for the hands (0.25 ± $0.03 m^2 \cdot kg^{-1}$) than the feet (0.12 ± $0.01 m^2 \cdot kg^{-1}$) ($P<0.05$). Surface area to volume ratio was also observed to be significantly greater for the hands (0.05 ± 0.03 $m^2 \cdot L^{-1}$) than the feet (0.04 ± 0.02 $m^2 \cdot L^{-1}$) ($P<0.05$). In addition, a positive correlation was observed between surface area to mass ratios for the hands and feet and heat loss during cooling ($r = 0.03$). However, no positive correlation was observed between surface area to volume ratios for the hands and feet and heat loss during cooling ($P>0.05$).

## 4.3 Physiological Responses

Table 4.3 shows mean physiological responses and rates of perceived exertion and thermal sensation at rest, during and immediately post exercise in the heat.

No significant interactions were observed for any of the physiological variables between trials. Significant increases in $\dot{V}O_2$, $\dot{V}CO_2$, VE, RPE, TS and BLa were observed with respect to time (main effect; $P<0.05$). After 20 minutes of exercise $\dot{V}O_2$ values represented 64.2 ± 24.9%, 63.4 ± 21.3% and 62.8 ± 28.1% of maximal values for NC, HC and FC trials respectively (Fig. 4.1). At the end of performance trial $\dot{V}O_2$ values were at 83.8 ± 27.7%, 87.6 ± 31.1% and 93.4 ± 31.8% for NC, HC and FC trials respectively. HR responses are presented in Fig. 4.2. Heart rate values following 20 minutes of exercise represented 87.5 ± 6.2%, 89.0 ± 6.5% and 86.7 ± 5.3% for NC, HC and FC trials respectively. Following the performance trial heart rate values represented 90.4 ± 8.7%, 92.7 ± 6.1%, 91.1 ± 5.0% for NC, HC and FC trials respectively.

Table 4.3 $\dot{V}O_2$, VE, RER, heart rate, local and overall RPE, thermal sensation and blood lactate values at rest, throughout exercise and at exhaustion.

| | | -15 | 0 | 5 | 10 | 20 | END |
|---|---|---|---|---|---|---|---|
| **$\dot{V}O_2$ (L·min$^{-1}$)** | *NC* | 0.35 ± 0.04 | 0.32 ± 0.04 | 1.68 ± 0.31 | 1.78 ± 0.43 | 1.66 ± 0.65 | 2.17 ± 0.72 |
| | *HC* | 0.33 ± 0.06 | 0.33 ± 0.06 | 1.41 ± 0.44 | 1.60 ± 0.38 | 1.64 ± 0.55 | 2.27 ± 0.81 |
| | *FC* | 0.29 ± 0.08 | 0.30 ± 0.09 | 1.46 ± 0.54 | 1.60 ± 0.58 | 1.63 ± 0.73 | 2.42 ± 0.82 |
| **VE (L·min$^{-1}$)** | *NC* | 11.25 ± 1.71 | 10.56 ± 1.33 | 51.58 ± 9.28 | 55.85 ± 15.47 | 51.96 ± 19.16 | 73.17 ± 20.03 |
| | *HC* | 11.08 ± 1.61 | 9.55 ± 1.45 | 42.99 ± 13.98 | 47.09 ± 14.39 | 50.42 ± 17.88 | 72.55 ± 24.59 |
| | *FC* | 9.67 ± 2.46 | 8.83 ± 2.02 | 43.92 ± 16.09 | 48.57 ± 19.37 | 46.88 ± 20.42 | 76.54 ± 19.31 |
| **RER** | *NC* | 0.85 ± 0.13 | 0.84 ± 0.13 | 1.05 ± 0.10 | 1.00 ± 0.10 | 0.91 ± 0.12 | 1.03 ± 0.15 |
| | *HC* | 0.93 ± 0.09 | 0.83 ± 0.08 | 1.02 ± 0.07 | 0.99 ± 0.09 | 0.99 ± 0.20 | 1.01 ± 0.19 |
| | *FC* | 0.90 ± 0.03 | 0.84 ± 0.05 | 1.04 ± 0.03 | 0.95 ± 0.02 | 0.99 ± 0.27 | 0.98 ± 0.12 |
| **HR (b·min$^{-1}$)** | *NC* | 64 ± 9 | 72 ± 11 | 134 ± 13 | 148 ± 12 | 158 ± 11 | 175 ± 12 |
| | *HC* | 69 ± 11 | 75 ± 13 | 134 ± 22 | 153 ± 15 | 161 ± 13 | 173 ± 9 |
| | *FC* | 68 ± 11 | 71 ± 7 | 132 ± 18 | 146 ± 15 | 157 ± 10 | 167 ± 4 |
| **RPE (A)** | *NC* | ---------------- | ---------------- | 13 ± 2 | 14 ± 2 | 17 ± 2 | 20 ± 0 |
| | *HC* | ---------------- | ---------------- | 13 ± 2 | 15 ± 1 | 17 ± 2 | 20 ± 1 |
| | *FC* | ---------------- | ---------------- | 13 ± 2 | 14 ± 1 | 16 ± 1 | 20 ± 0 |
| **RPE (O)** | *NC* | ---------------- | ---------------- | 11 ± 3 | 12 ± 3 | 14 ± 3 | 17 ± 1 |
| | *HC* | ---------------- | ---------------- | 11 ± 1 | 13 ± 2 | 14 ± 2 | 16 ± 2 |
| | *FC* | ---------------- | ---------------- | 10 ± 2 | 12 ± 3 | 13 ± 2 | 15 ± 2 |
| **TS** | *NC* | ---------------- | ---------------- | 5 ± 1 | 6 ± 1 | 7 ± 1 | 7 ± 1 |
| | *HC* | ---------------- | ---------------- | 5 ± 1 | 6 ± 1 | 6 ± 1 | 6 ± 1 |
| | *FC* | ---------------- | ---------------- | 5 ± 1 | 6 ± 1 | 6 ± 0 | 6 ± 0 |
| **BLa (mmol)** | *NC* | 0.76 ± 0.15 | 0.77 ± 0.13 | 3.99 ± 1.65 | 4.84 ± 1.42 | 5.24 ± 2.50 | 5.48 ± 2.31 |
| | *HC* | 0.90 ± 0.31 | 0.84 ± 0.34 | 3.62 ± 1.70 | 4.03 ± 2.46 | 4.63 ± 1.18 | 6.07 ± 0.94 |
| | *FC* | 1.04 ± 0.52 | 0.93 ± 0.38 | 3.55 ± 0.75 | 4.11 ± 1.32 | 4.39 ± 1.43 | 5.70 ± 1.61 |

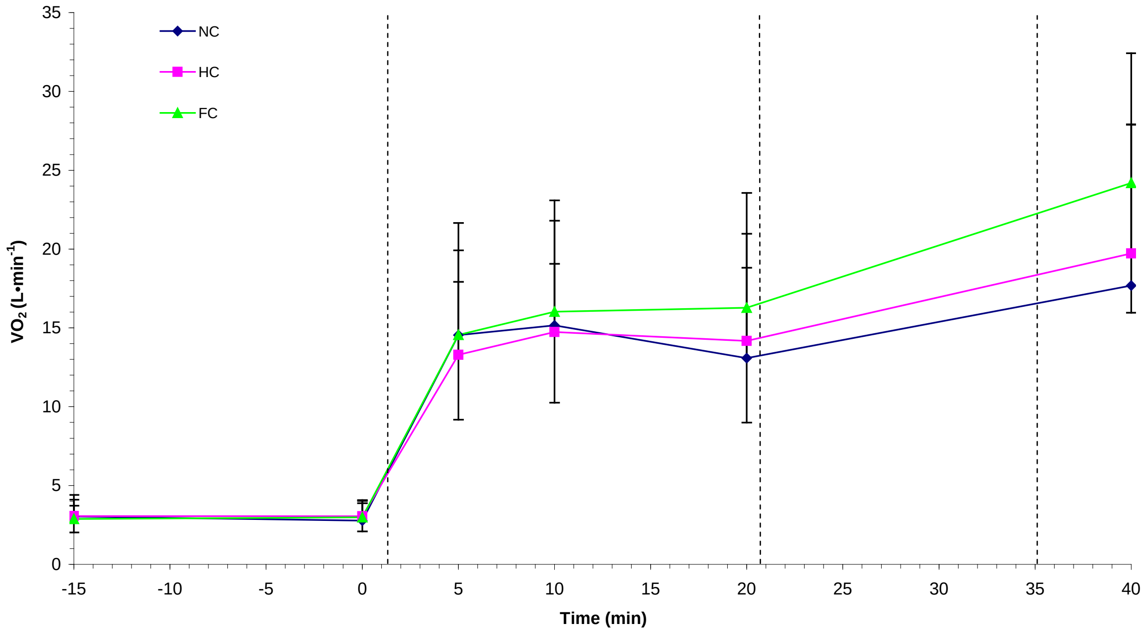


Figure 4.1. Oxygen consumption ($\dot{V}O_2$ L·min$^{-1}$) at rest, during 20 minutes of exercise, cooling and performance in hot conditions.

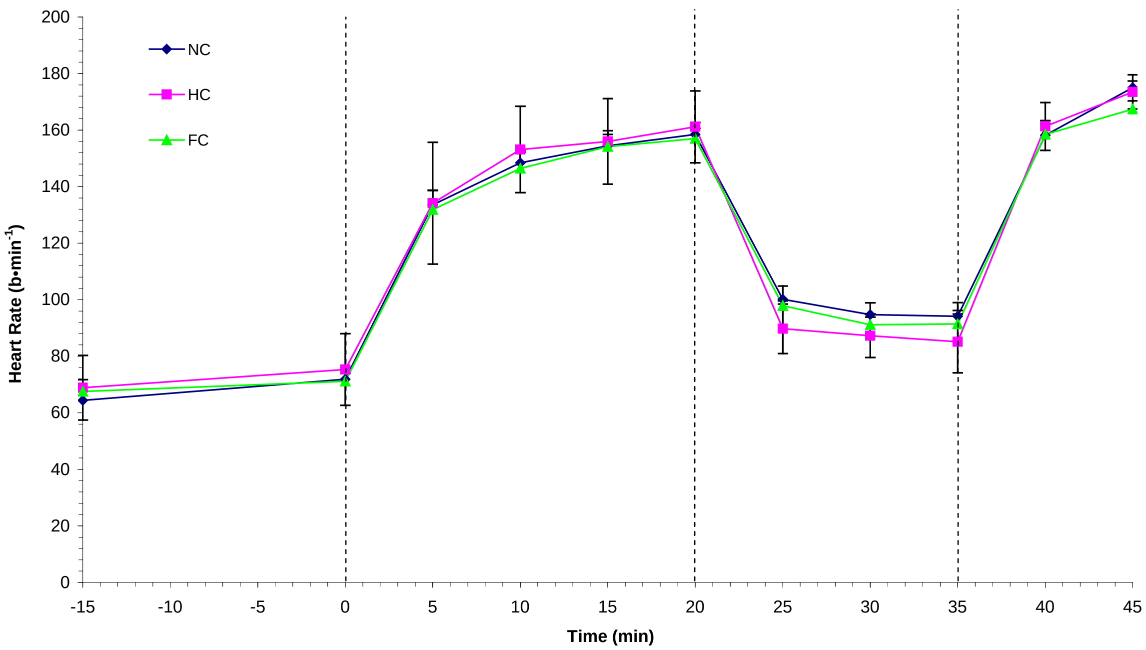


Figure 4.2. Heart rate (b·min$^{-1}$) at rest, during 20 minutes of exercise, cooling and performance in hot conditions.

## 4.4 Core Temperature

No significant differences were observed for $T_{re}$ between trials ($P<0.05$). $T_{re}$ increased from rest (37.3 ± 0.4°C, 37.0 ± 0.3°C, 37.0 ± 0.7°C) by 20 minutes (37.7 ± 0.8°C, 37.2 ± 0.4°C, 37.1 ± 0.7°C) representing increases of; 0.4 ± 0.5°C, 0.2 ± 0.2°C, 0.1 ± 0.2°C) for the NC, HC and FC trials respectively.

No significant interaction between trials was observed for $T_{au}$ (Fig. 4.3). However, main effects for trial and time were observed ($P<0.05$). $T_{au}$ increased significantly from rest (36.2 ± 0.2°C, 36.1 ± 0.5°C, 36.1 ± 0.3°C) after 20 minutes of exercise (37.5 ± 0.5°C, 37.3 ± 0.3°C, 37.2 ± 0.2°C) ($P<0.05$) for the NC, HC and FC trials, representing increases in $T_{au}$ of 1.3 ± 0.2°C, 1.2 ± 0.4°C and 1.1 ± 0.2°C respectively. At the end of the cooling period $T_{au}$ had decreased by 0.5 ± 0.5°C, 0.7 ± 0.3°C and 0.3 ± 0.3°C for NC, HC and FC trials respectively. $T_{au}$ was lower after cooling than before in both the NC (37.0 ± 0.3 °C) and HC (36.1 ± 0.9°C) trials. $T_{au}$ did not significantly decrease during FC (0.3 ± 0.3°C). There was no significant difference in $T_{au}$ between NC and either HC or FC at the end of performance trial.

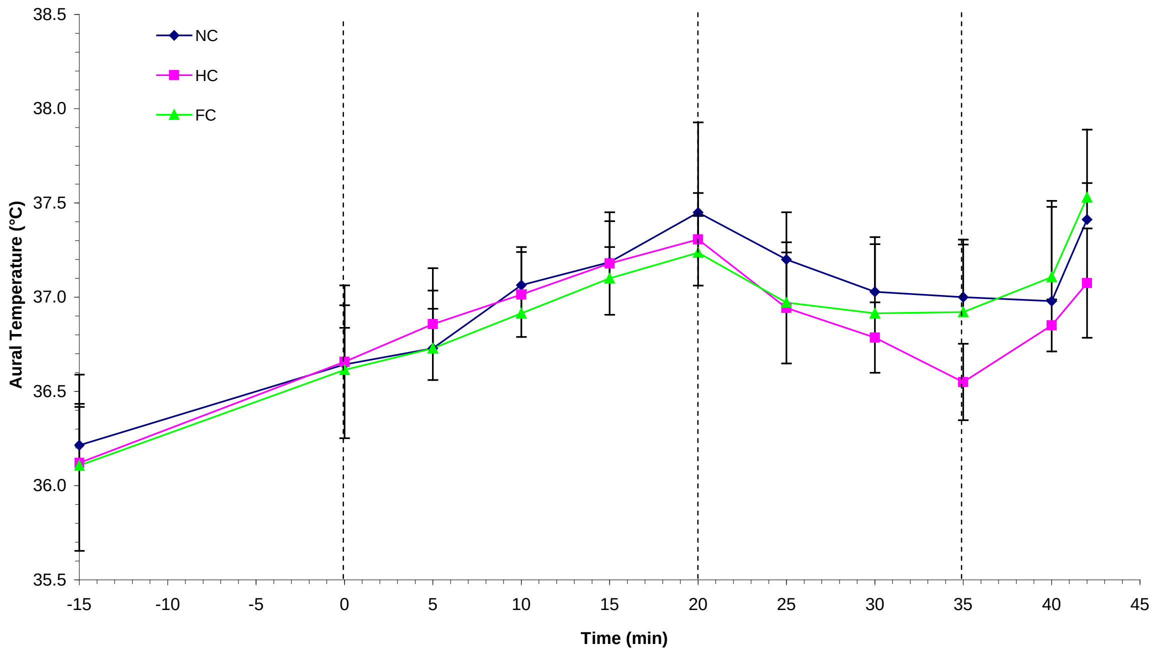


Figure 4.3. Aural temperature ($T_{au}$ °C) at rest, during 20 minutes of exercise, cooling and performance in hot conditions.

## 4.5 Skin Temperature

No significant differences were observed for MST between the three trials (Fig. 4.4). However a significant main effect for time was observed ($P<0.05$). In addition, no significant differences were observed between the three trials for chest ($T_{ch}$), thigh ($T_{th}$) or calf ($T_{ca}$) skin temperatures. Upper arm skin temperature ($T_{arm}$), however, did show a significant interaction between the three trials following cooling ($P<0.05$) (Fig. 4.5). The HSD value for this interaction was 1.0°C. There were no significant differences between the three trials in the initial 20 minute exercise period. After five minutes of cooling, $T_{arm}$ decreased more during the HC trial (37.3 ± 0.6°C to 35.6 ± 0.7°C) than in NC (37.0 ± 0.6°C to 36.8 ± 0.6°C) and FC (36.9 ± 0.4°C to 36.4 ± 0.4°C). After 15 minutes of cooling $T_{arm}$ was significantly lower in HC (35.0 ± 1.0°C) than FC (36.2 ± 0.7°C) and NC (36.7 ± 0.4°C). There were no significant differences in $T_{arm}$ between

FC and NC trials. At the end of the performance trial $T_{arm}$ was not significantly different between any of the three trials (HC; 37.3 ± 0.5°C, FC; 37.3 ± 0.5°C, NC; 37.1 ± 0.9°C).

There were no significant interaction observed between trials for hand or foot temperature (P>0.05). A main effect for time was observed for both hand and foot temperature (P<0.05). Hand temperature decreased significantly more (23.8 ± 1.6°C) than foot temperature (18.0 ± 3.0°C) in the respective cooling trials (P<0.05) to 12.1 ± 1.3°C and 13.7 ± 2.1°C respectively (Fig. 4.6).

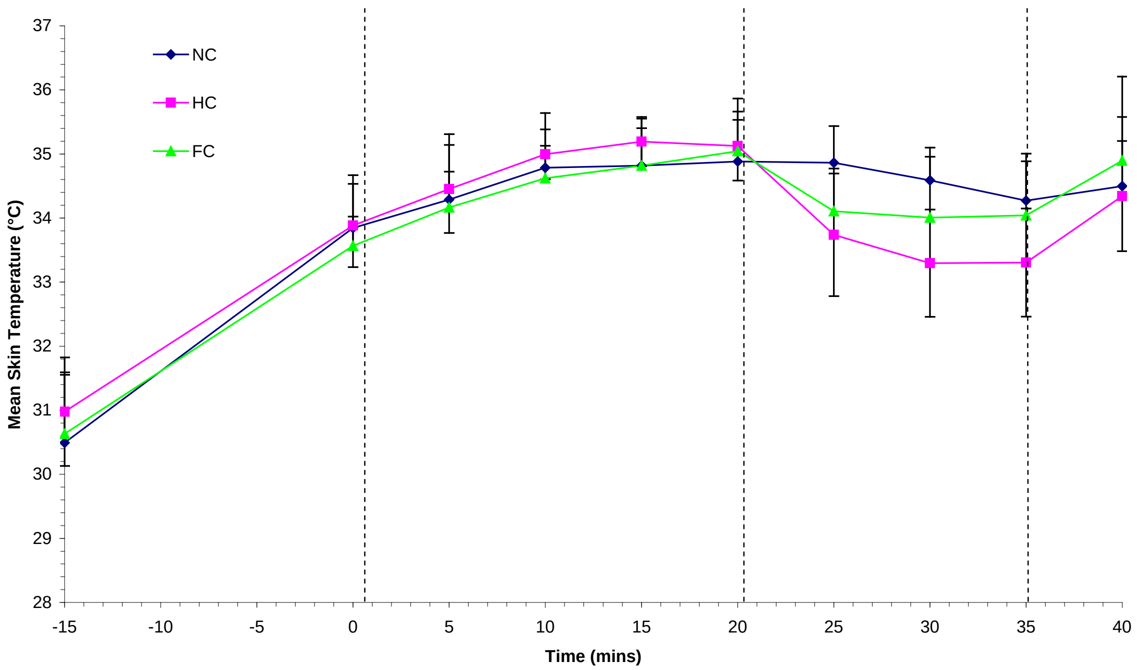


Figure 4.4. Mean Skin Temperature values throughout the three experimental trials.

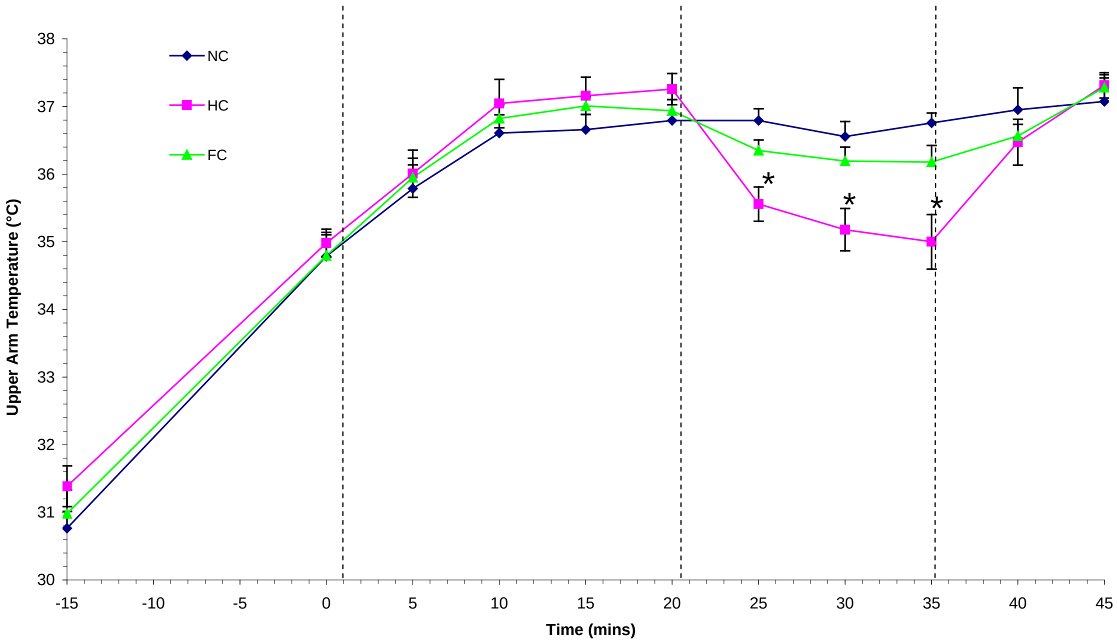


Figure 4.5. Upper arm skin temperature for all three experimental trials (* = significantly different from NC and FC).

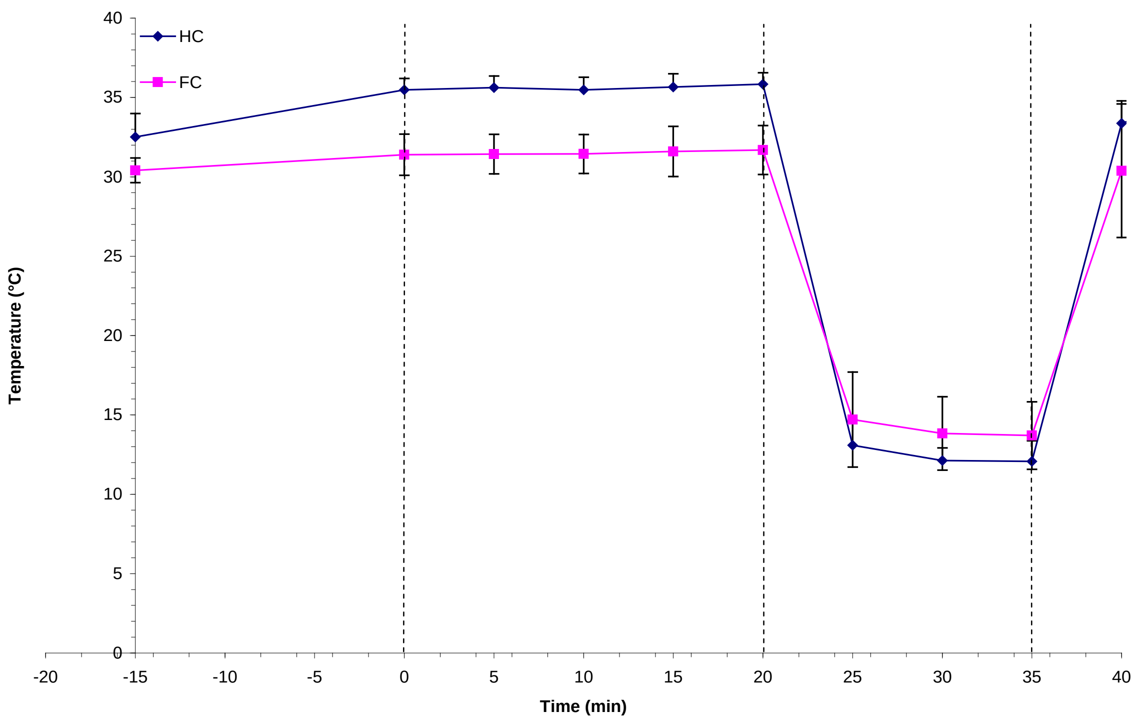


Figure 4.6. Hand temperature (HT) and foot temperature (FT) at rest, during 20 minutes of exercise, cooling and performance in hot conditions for the HC and FC trials only.

## 4.6 Heat Loss

Heat loss was significantly greater during HC (140 ± 17W) than in FC (121 ± 9W) (P<0.05) (Fig. 4.7) over the duration of the cooling period.

## 4.7 Skin Blood Flow

No significant interactions were observed between trials for skin blood flow at the back (Fig. 4.8), thigh (Fig. 4.9) or calf (Fig. 4.10). Furthermore there were no significant main effects observed for the % change from rest of skin blood flow at any of the measured sites throughout exercise. Skin blood flow was not significantly different between trials at the end of performance trial. Correlation analysis between skin blood flow and $T_{au}$ following 20 minutes of exercise produced no significance at either the back (r = 0.16), the thigh (r = -0.02) or the calf (r = 0.08) (P>0.05). In addition, there were no significant correlations between skin blood flow and $T_{au}$ at the end of performance time (P>0.05).

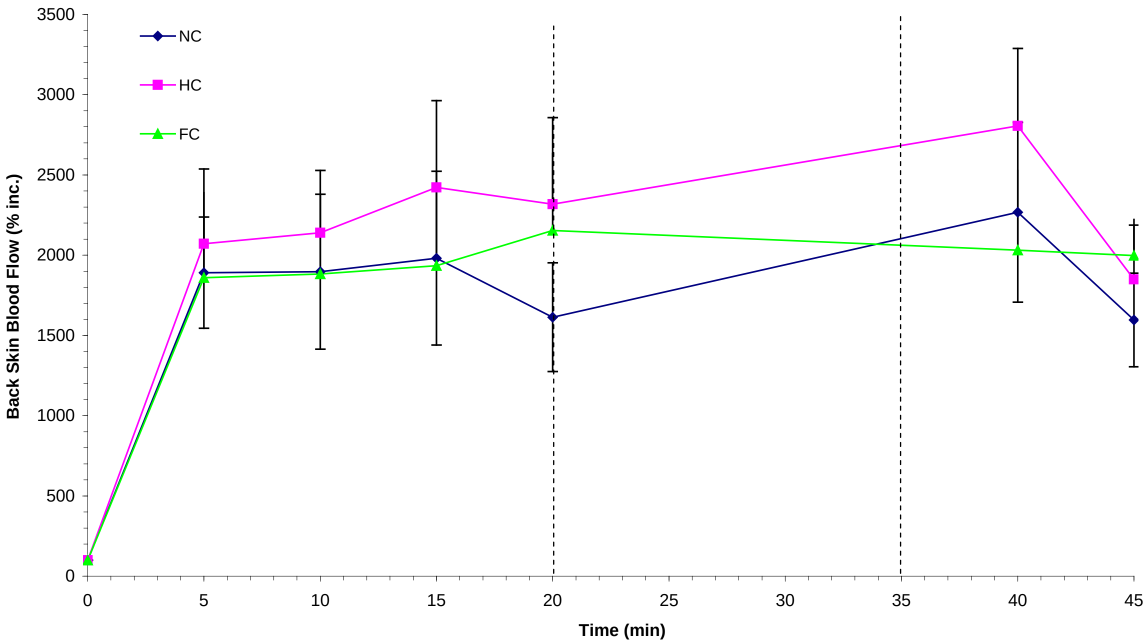


Figure 4.8. % increase in back skin blood flow throughout the trials.

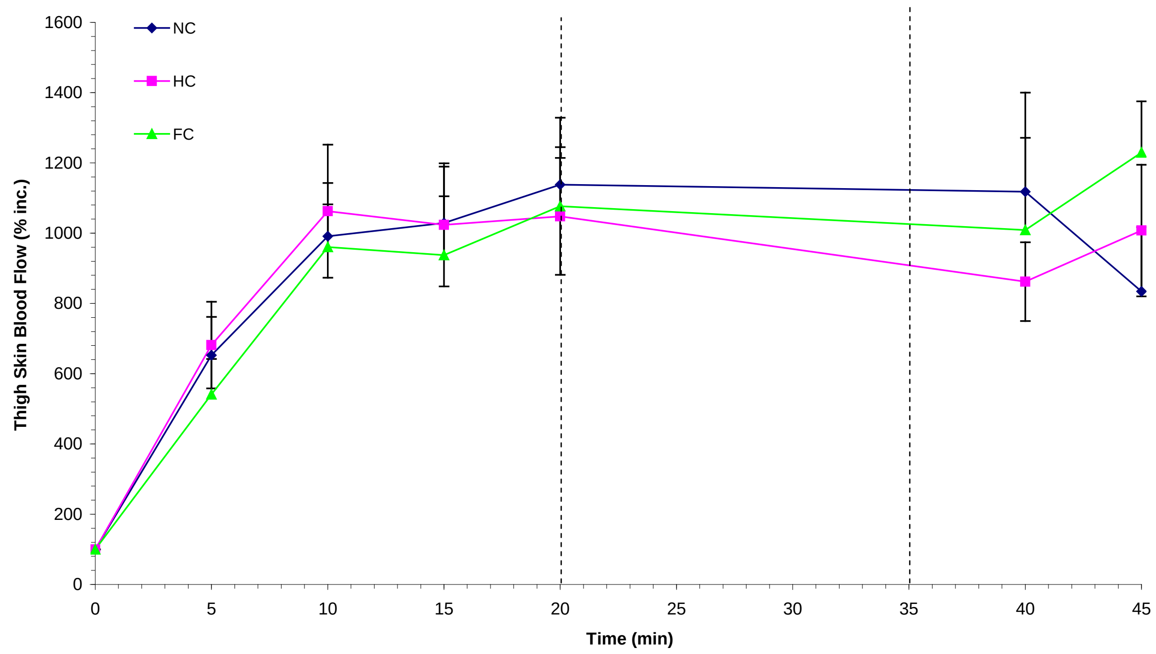


Figure 4.9. % increase in thigh skin blood flow throughout the trials.

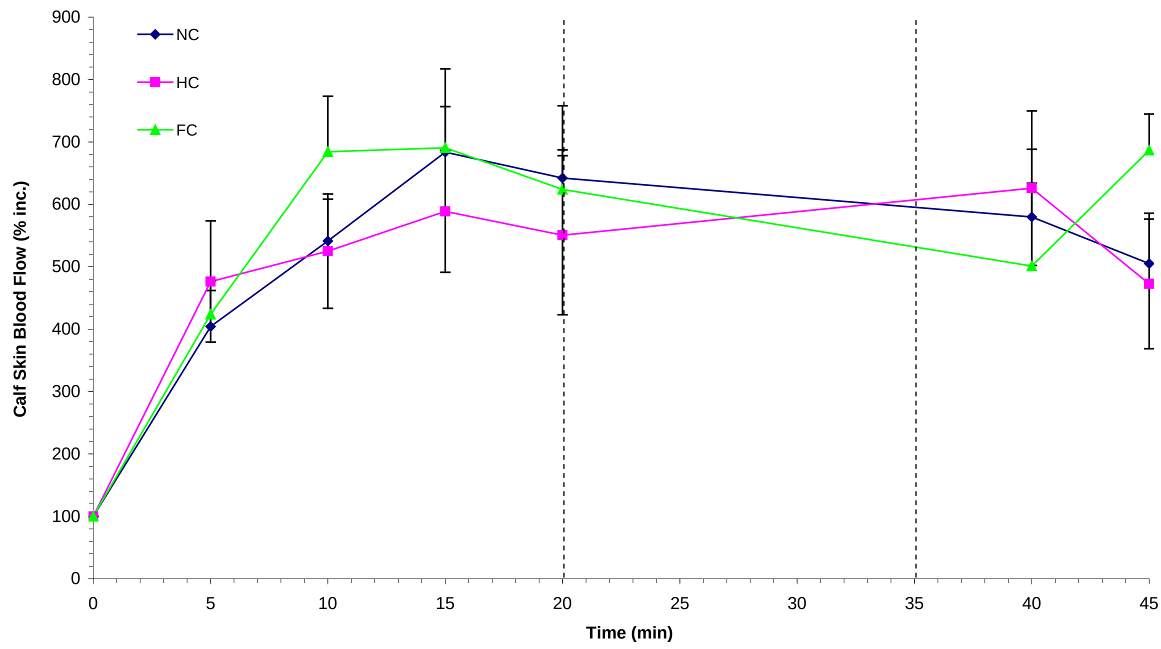


Figure 4.10. % increase in calf skin blood flow throughout the trials.

## 4.8 Local Sweat Rates

No significant interactions were observed between trials for local sweat rate at the forehead, scapula, thigh or calf. However, significant main effects for time for sweat rate were observed across the three trials. Significant increases were seen for $SR_F$, $SR_B$ and $SR_T$ from resting at room temperature to resting in the heat. $SR_F$ $SR_B$ and $SR_T$ rose significantly from rest at room temperature following 20 minutes of exercise (P<0.05) (Fig. 4.11, 4.12 and 4.13). All three sites then significantly decreased following cooling (P<0.05 main effect for time). At the end of the performance trial $SR_F$, $SR_B$ and $SR_T$ were similar to values directly before cooling. Sweat rates significantly increased from the end of cooling to the end of performance (P<0.05) to similar values as at the end of the initial exercise bout.

$SR_C$ did not significantly increase from rest at room temperature to resting in the heat (Fig. 4.14). $SR_C$ significantly increased by the end of 20 minutes of exercise by; 506 ± 253nl·min$^{-1}$, 418 ± 146nl·min$^{-1}$ and 515 ± 228nl·min$^{-1}$ for NC, HC and FC trials respectively. $SR_C$ then significantly decreased from the end of exercise to the end of cooling by; 293 ± 107nl·min$^{-1}$, 409 ± 122nl·min$^{-1}$ and 346 ± 184nl·min$^{-1}$ for NC, HC and FC respectively. At the end of the performance trial $SR_C$ had significantly increased from the end of cooling by; 227 ± 97nl·min$^{-1}$, 319 ± 112nl·min$^{-1}$ and 211 ± 192nl·min$^{-1}$ for NC, HC and FC respectively.

Correlation analysis between individual local sweat rates and $T_{au}$ throughout the whole trial produced no significant relationships at the forehead (r = 0.08) (Fig. 4.15), scapula (r = 0.08) (Fig. 4.16), thigh (r = 0.07) (Fig. 4.17) or calf (r = 0.05) (Fig. 4.18) (P>0.05). Correlation between local sweat rates and $T_{au}$ following cooling also produced no significance (P>0.05).

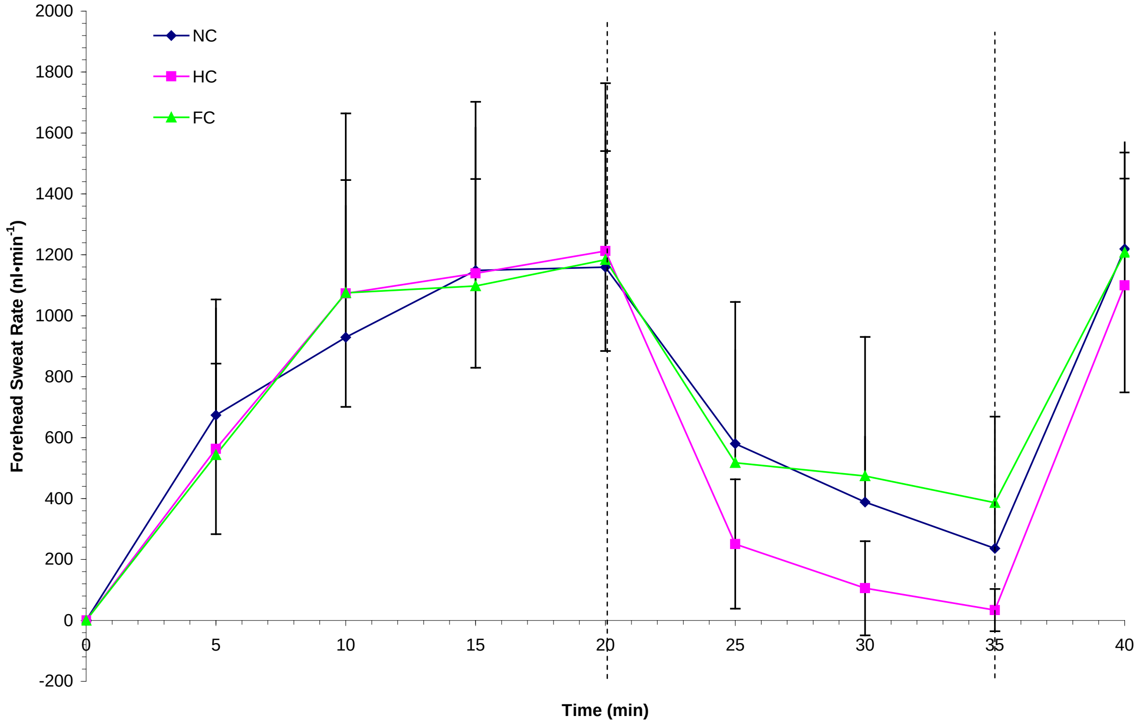


Figure 4.11. Relative change in forehead sweat rate from baseline.

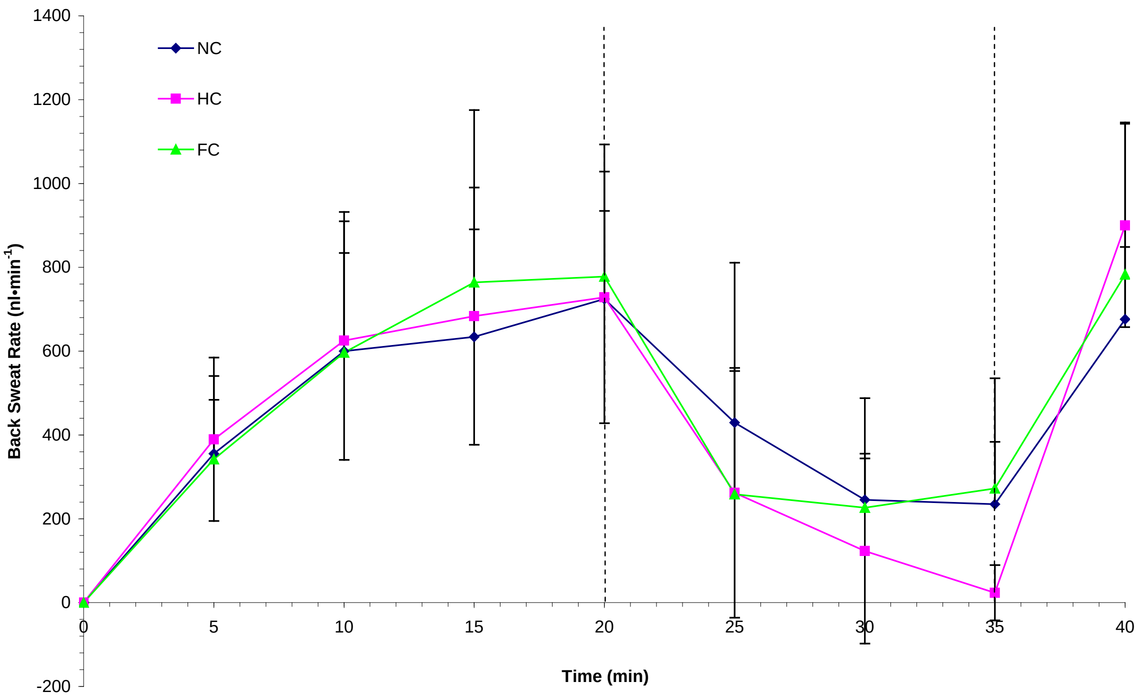


Figure 4.12. Relative change in scapula sweat rate from baseline.

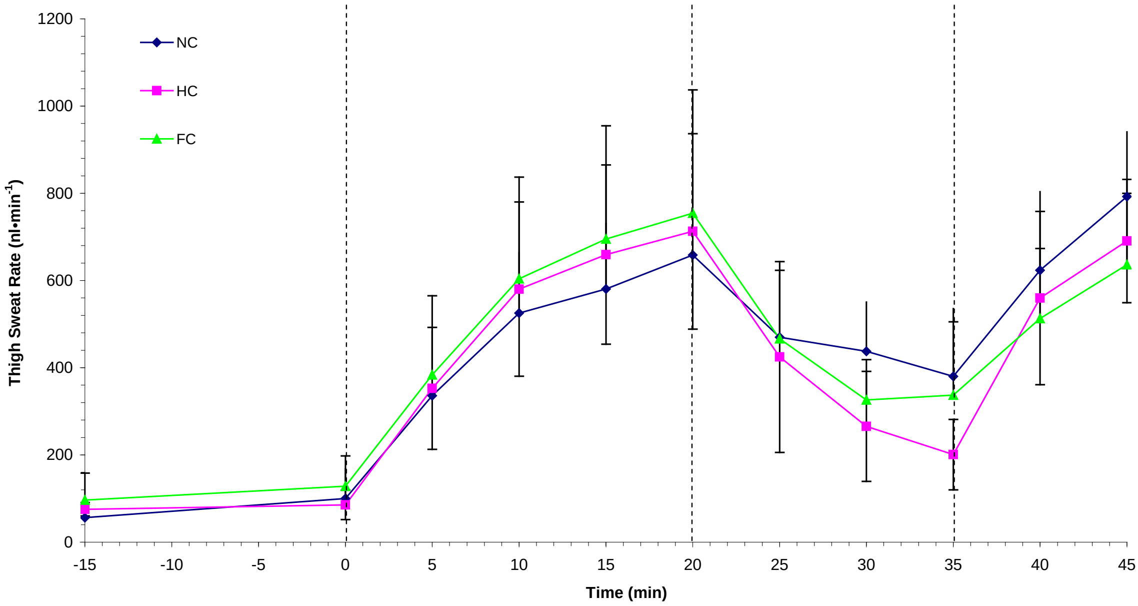


Figure 4.13. Thigh sweat rate throughout the three experimental trials.

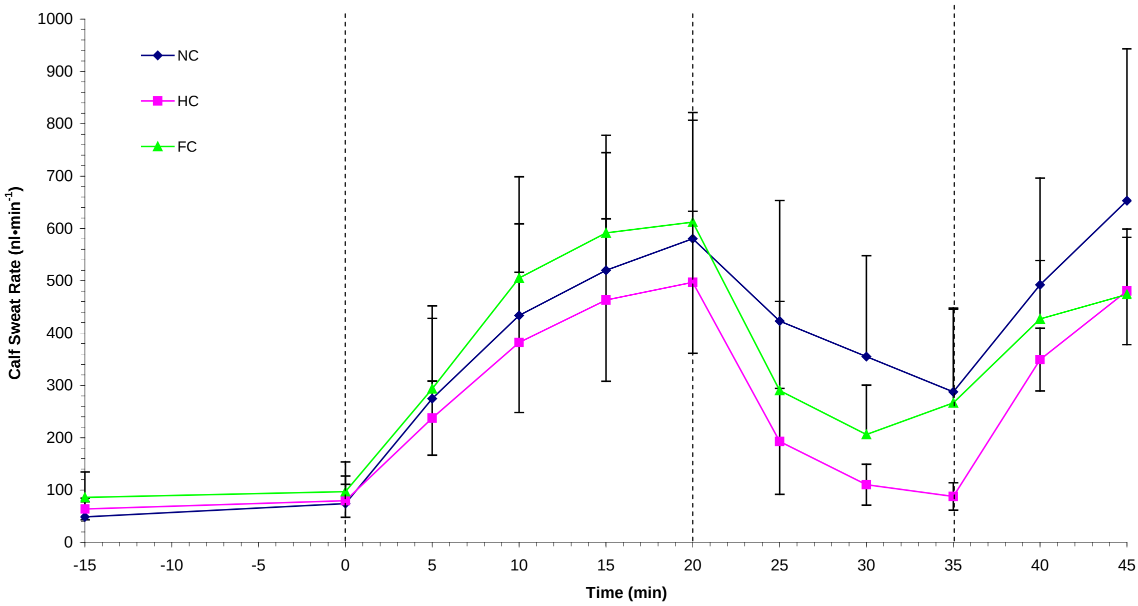


Figure 4.14. Calf sweat rate throughout the three experimental trials

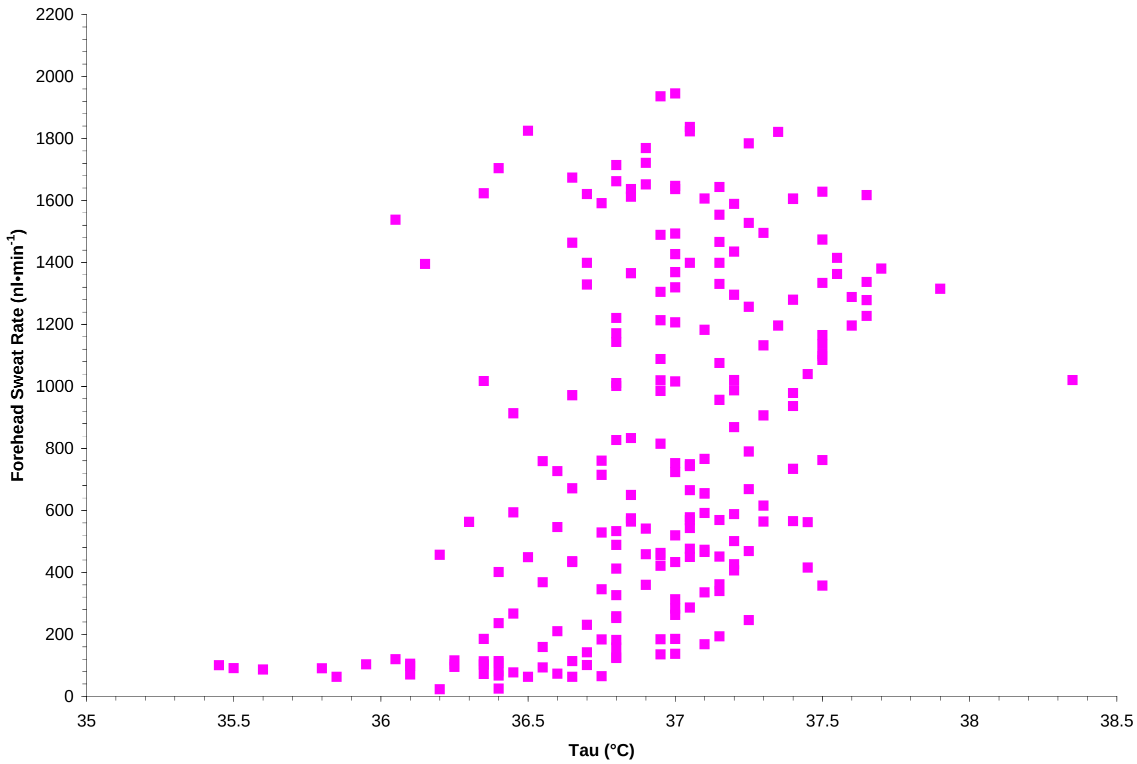


Figure 4.15. Forehead sweat rate vs. $T_{au}$ throughout the three experimental trials.

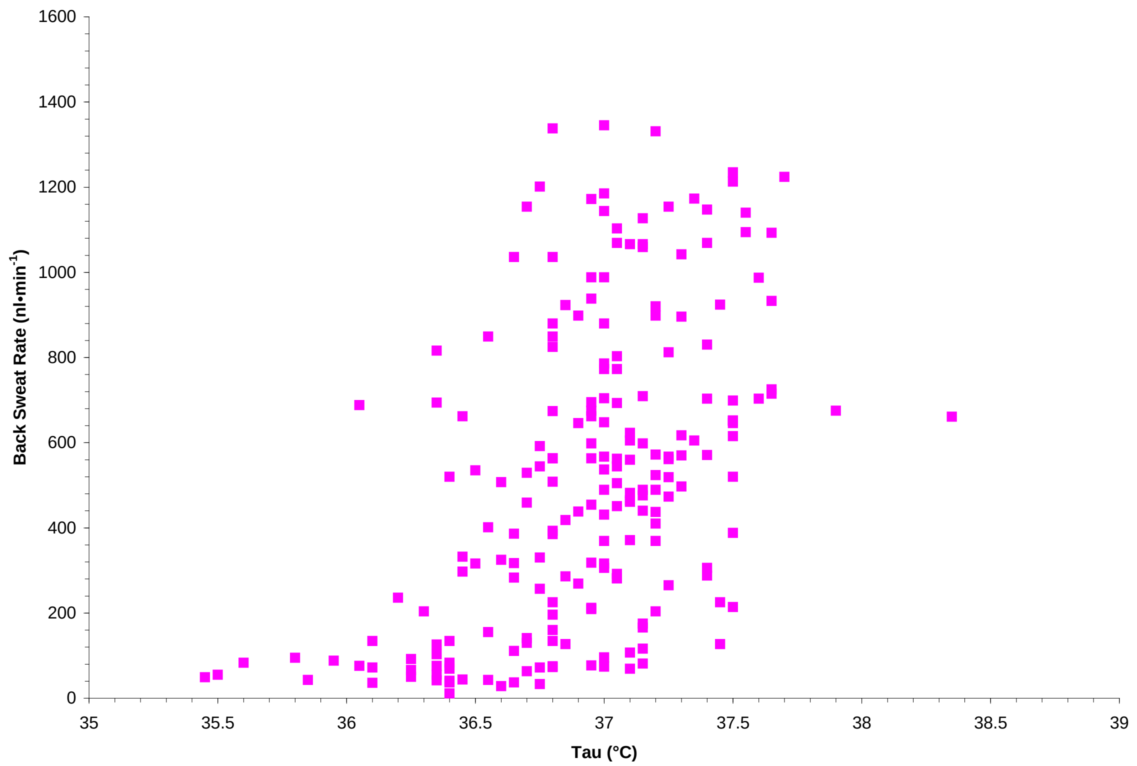


Figure 4.16. Back sweat rate vs. $T_{au}$ throughout the three experimental trials.

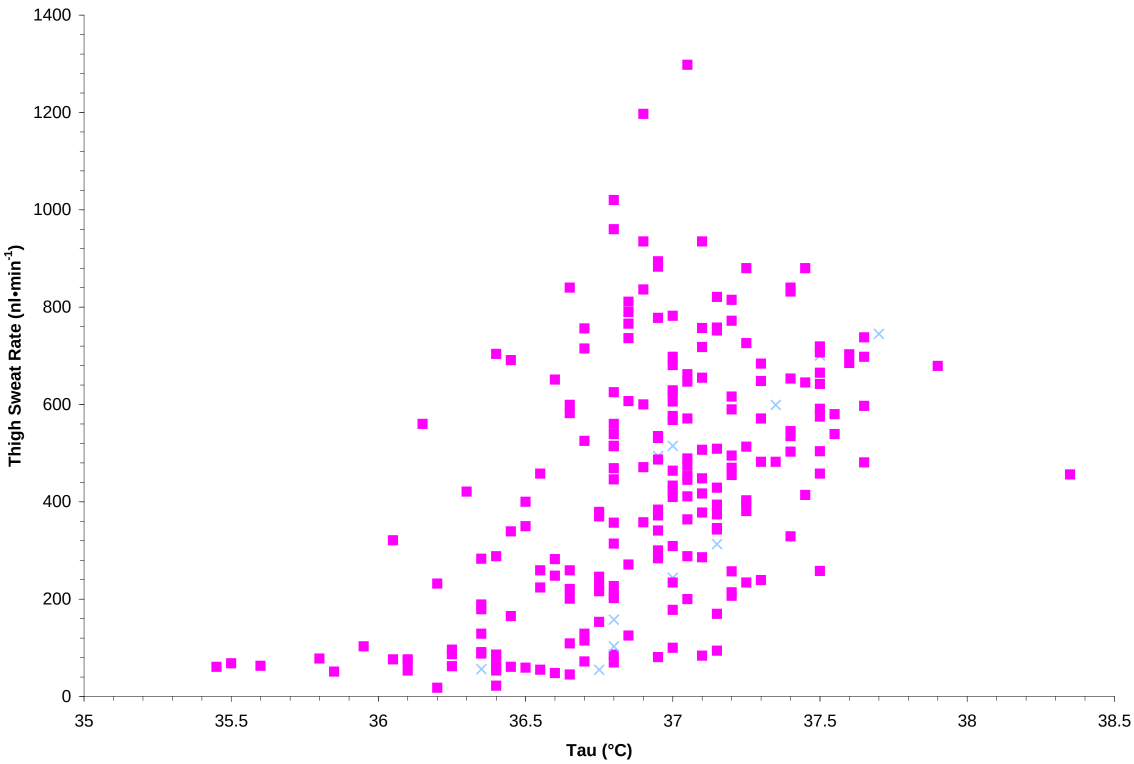


Figure 4.17. Thigh sweat rate vs. $T_{au}$ throughout the three experimental trials.

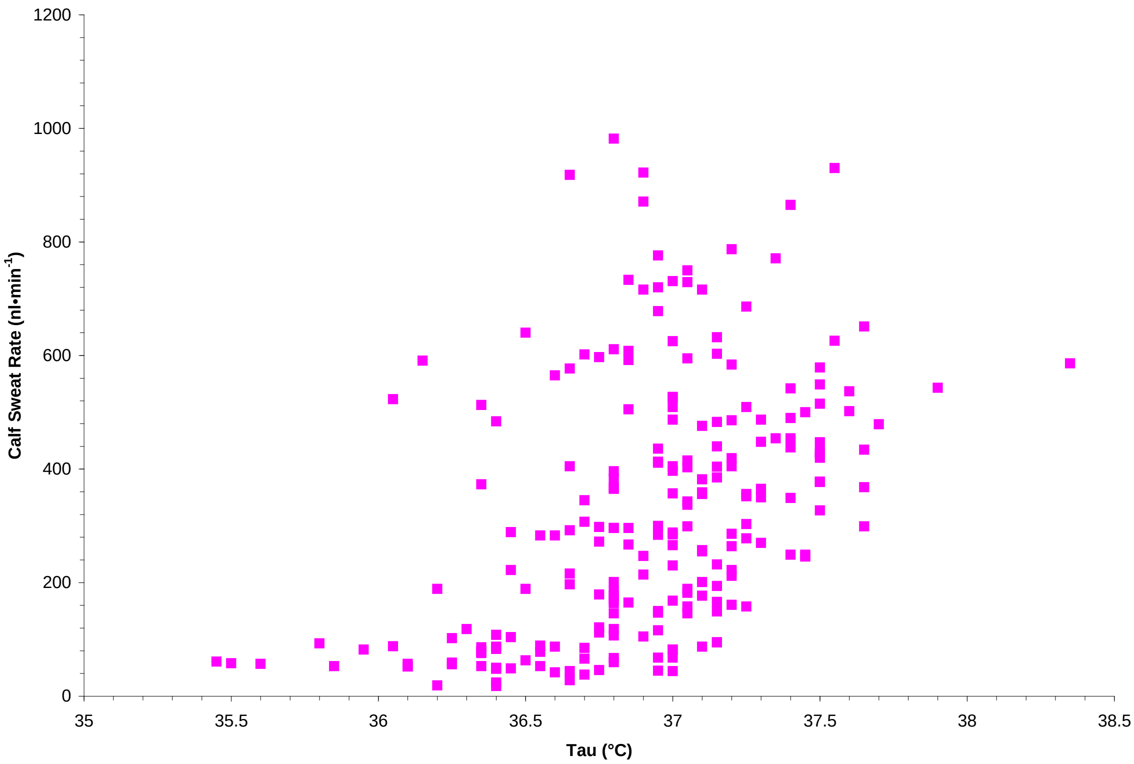


Figure 4.18. Calf sweat rate vs. $T_{au}$ throughout the three experimental trials.

## 4.9 Heat Flow

When compared to the first five minutes of cooling there was a significant decrease in heat flow at the end of cooling was observed for both HC (decrease of 158 ± 72W·m$^2$) and FC (decrease of 238 ± 99W·m$^2$) ($P<0.05$) but no significant difference was observed between the two conditions (Fig. 4.19).

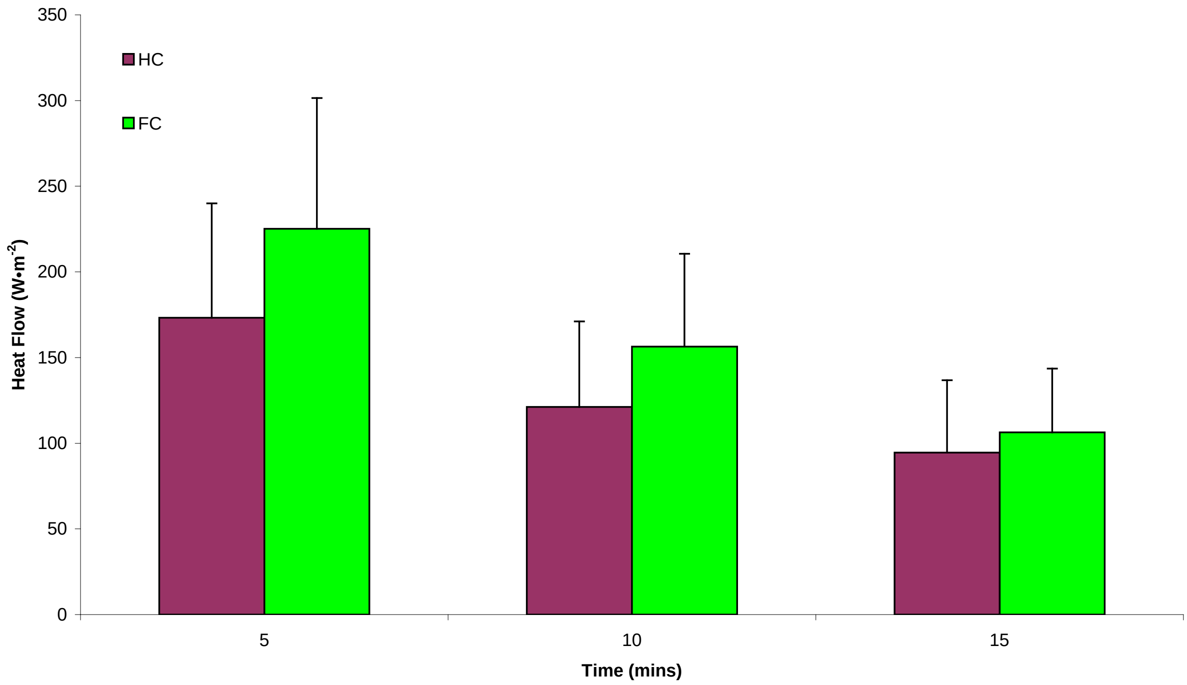


Figure 4.19. Heat flow the hands/feet during 15 minutes of cooling.

## 4.10 Performance Time

No significant differences were found between trials for performance time (NC = 6.95 ± 3.42mins, HC = 8.19 ± 3.16mins, FC = 6.51 ± 2.61mins) (Fig. 4.20). No significant correlation was observed for performance time against $T_{au}$ at the end of performance. Furthermore, there was no significant correlation observed between either performance time and $T_{au}$ at the end of cooling ($r = 0.07$) or between performances during NC, HC and FC ($P>0.05$).

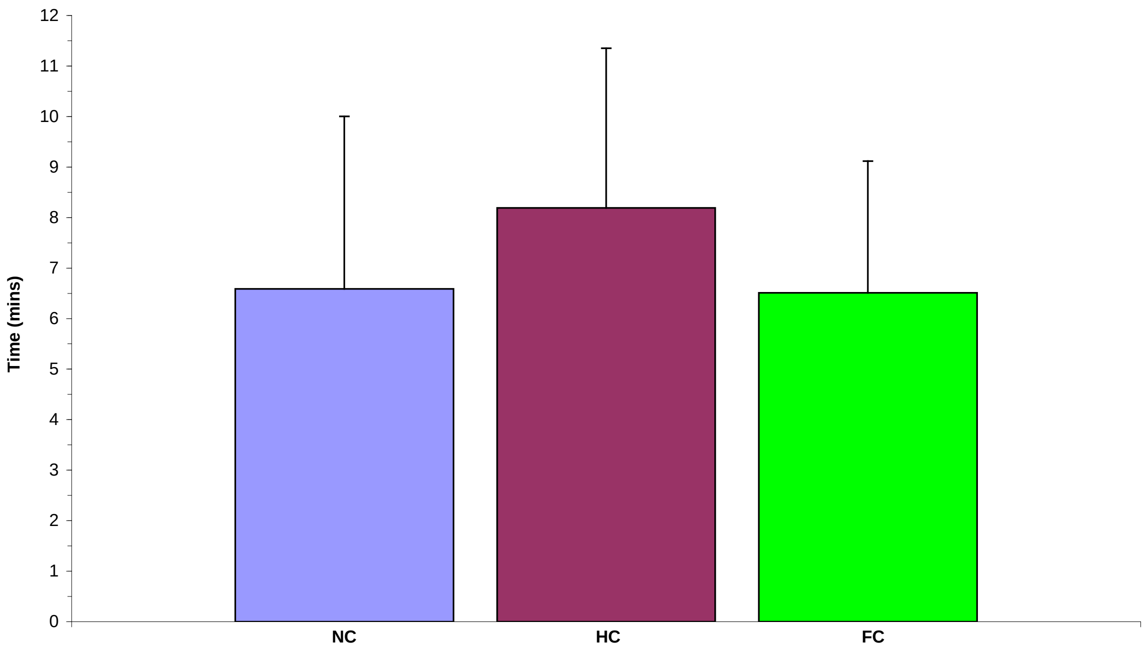


Figure 4.20. Performance end times for each trial.

# 5.0 Discussion

The main aim of this study was to compare the effects of hand and foot cooling on upper body exercise performance in the heat. A significant main effect for trial and time for $T_{au}$ was observed. $T_{arm}$ was observed to decrease significantly more during HC than NC or FC. However, there were no differences observed for performance time between trials. No differences were observed for MST, $T_{ch}$, $T_{th}$, $T_{ca}$, skin blood flow or local sweat rates. Heat loss was observed to be significantly greater during HC than FC.

## 5.1 Core Temperature

### 5.1i Rectal Temperature

$T_{re}$ demonstrated no differences between trials or over time. This was also the case for the $\Delta T_{re}$ values. Two possible factors for the lack of increase in $T_{re}$ could be the exercise duration and the responsiveness of $T_{re}$. $T_{re}$ has been observed to be less responsive than $T_{au}$ during upper body exercise (Sawka, 1984; Price and Mather, 2004). Therefore longer exercise periods may be required to elicit a significant increase in $T_{re}$. The results from the current study correspond with the results of Sawka et al. (1984) in that after 20 minutes of exercise at similar metabolic rates ($\dot{V}O_2 \sim 1.6\ l\cdot min^{-1}$) $T_{re}$ values demonstrate very little change (~0.2°C).
Similarly, the results of Goosey-Tolfrey et al. (2008) show minimal changes in core temperature using a telemetry pill in the first 20 minutes of exercise (~0.25°C). $T_{re}$ was not observed to increase significantly during the performance trial although all three trials did demonstrate a tendency to increase.

Performance times rarely exceeded ten minutes and therefore, considering the lack of response found in the previous 20 minutes of exercise, it is unlikely that there was a long enough time period to allow for significant increases in $T_{re}$. Indeed, studies that have demonstrated significant $T_{re}$ increases have used significantly longer exercise periods (Livingstone et al., 1989). A longer exercise period was not used in the current study due to difficulties reported by the participants in pilot experiments in not being able to perform more than 20 minutes of arm cranking at 60% peak power. The choice was made to maintain the exercise intensity at 60% peak power for 20 minutes rather than decrease the intensity and perform for a longer time period in order to ensure the exercise intensity was comparable with previous studies (Sawka et al., 1984; Pimental et al., 1984; Price and Campbell, 2002). With a lower intensity, participants may have been able to perform for longer than 20 minutes and subsequently core temperatures and the drive for heat loss would increase.

The mode of exercise could also be a factor in the small $\Delta T_{re}$. It has been previously hypothesised that differences in metabolic heat production between upper and lower body exercise may elicit different responses depending on the site of core temperature measurement (Sawka et al., 1989). This is supported by the results of Sawka et al. (1984) where $T_{re}$ was observed to be significantly lower during arm crank exercise than cycling exercise at the same relative intensity (60% $\dot{V}O_{2pk}$). This reflects the differences in absolute heat production between upper and lower body exercise. The redistribution of blood flow to the working muscles from less active areas may also be a factor in $T_{re}$ responses. In order to supply a greater blood flow to the upper body as exercise begins the local vasodilation of arterioles in the arms will be accompanied by vasoconstriction elsewhere. Blood flow will therefore be reduced to areas of the body that are not immediately required for exercise such as the splanchnic circulation (Ahlborg and Felig, 1982) and in the case of this study, most likely the lower body skeletal musculature during upper body exercise (Hopman et al., 1993). This reduction in blood flow will result in a reduced volume of warm blood circulating around the lower body. This is not the case at the site of $T_{au}$ measurement as blood flow to the head will not be reduced in this way. This could give rise to the more responsive trend of $T_{au}$ during upper body exercise. In addition, at the site of measurement for $T_{re}$ there is a significantly greater tissue mass than at the site of measurement for $T_{au}$. Therefore a greater amount of exercise and energy expenditure would be required in order to instigate increases in $T_{re}$ compared to $T_{au}$ as a result of thermal inertia (Hassan and Togawa, 2001).

No significant changes in $T_{re}$ occurred during the cooling period for HC, FC or NC nor were any significant differences between the trials found during cooling. This indicates that cooling techniques had little effect on $T_{re}$ following 20 minutes of exercise in the heat.

5.1.ii Aural Temperature

No significant interaction was found for $T_{au}$. However, a main effect between trials was observed for both absolute $T_{au}$ values and $\Delta T_{au}$. Although no significant interactions were observed between trials for $T_{re}$ and $T_{au}$, $T_{au}$ significantly increased during the initial 20 minutes of exercise (main effect for time $P<0.05$). This is another indication of the greater responsiveness of $T_{au}$ as noted in previous studies (Price and Mather, 2004). The increases in $T_{au}$ in the current study (~1.2 ± 0.2°C) correspond with those found previously for upper body exercise in the heat (increase of 1.6 ± 0.7°C) over 60 minutes (Price and Campbell, 2002).

The influence of the external environment on $T_{au}$ compared with $T_{re}$ could be considered a potential factor in this difference due to the relative distances between the thermistors and the environment ($T_{re}$ = 10cm, $T_{au}$ = 2cm). However the aural thermistor was heavily insulated with cotton wool (Kurz et al., 1993) and will have been insulated from the influence of environmental temperature. Whilst 20 minutes was not sufficient time in which to elicit a significant response in $T_{re}$, $T_{au}$ was significantly greater than resting values after 20 minutes (~1.0°C). Indeed similar values to the current study were observed after 60 minutes of intermittent exercise (~37°C) for wheelchair participants (Goosey-Tolfrey et al., 2008) and following 30 minutes of continuous arm crank exercise at 50% $\dot{V}O_{2pk}$ (~37.3°C) (Price and Mather, 2004). Therefore the increase observed in $T_{au}$ in the current study is comparable to previous studies.

$T_{au}$ decreased more during HC than NC or FC and demonstrates cooled blood returning from the hands to the core and reducing core temperature as observed previously (Livingstone et al., 1989; House et al., 1997). Placing the hands in cool water with an elevated core temperature provides a large drive for heat flow between the hands and the water. This results in a much more effective heat loss from the hands to the water than would occur with a lower core temperature, due to increased cutaneous blood flow in the hands. Such a cooling mechanism provided more effective cooling than for resting with no cooling being undertaken. The decrease in $T_{au}$ with HC noted in the current study (0.8°C) though is not as great as has been observed in previous studies. For example, House et al. (1997) observed a 1.3°C decrease in $T_{au}$ after 15 minutes of HC and Goosey-Tolfrey et al. (2008) observed a 1.2°C decrease with just 10 minutes of HC. As previously discussed for $T_{re}$, this is likely due to the higher $T_{au}$ recorded prior to cooling (House et al., 1997 = 38.5°C; Goosey-Tolfrey et al., 2008 = 38.7°C) compared with the current study (37.3°C) providing a greater drive for heat loss.

Based on the results found in the current study FC does not appear to be as effective as HC. In addition FC does not appear to have any beneficial cooling effects during upper body exercise. In discussing differences between hand and foot cooling there are many factors to consider. Firstly, as previously mentioned, the exercise mode could have had an effect. The increased vasodilation and blood flow in the arm during exercise will allow a greater flow of the cooled blood to and from the hands. Furthermore, during upper body exercise blood flow to the leg is decreased (Hopman et al., 1993; Bottoms, 2008). Therefore the volume of blood in the leg or foot available for cooling may be lower than during lower body exercise. When the feet were cooled, the cooler blood in the skin of the feet may not be delivered as efficiently to the core as may be expected for HC due to a decrease in leg blood flow. FC would therefore not be as effective as HC. In addition, the hands were observed to have a greater surface area to mass ratio than the feet, providing a much greater cooling potential. The feet also contain much larger, denser bones than the hands (Thompson and Floyd, 2004) which may hinder heat loss. The greater potential of the hands as a site for heat loss is supported by results observed for heat loss during cooling, which demonstrated a greater heat loss from the hands (140 ± 17W) than the feet (121 ± 9W) (P=<0.05) during the respective cooling methods.

$T_{au}$ demonstrated a trend to remain lower at the end of performance trial following HC (37.1 ± 0.3°C) than following FC (37.5 ± 0.1°C) but not NC (37.4 ± 0.5°C). This follows on from the effects of the cooling intervention where $T_{au}$ decreased more during HC. Consequently, the participants began the performance trial with a lower $T_{au}$ following HC than with FC. Therefore, if $T_{au}$ increased at the same rate in both performance trials then it will always be lower in the HC trial than FC. $T_{au}$ rose significantly during the performance trial in NC, HC and FC in the trials where performance time exceeded five minutes (37.3 ± 0.3°C) (n=14). However, there were no significant increases in $T_{au}$ at five minutes of performance or at the end of performance for trials where performance time was shorter than or equal to five minutes (36.8 ± 0.4°C) (n=8).

There were no significant differences observed for $T_{au}$ between the three trials after the first five minutes or at the end of the performance trials for those performance times shorter than or approximately five minutes (n=7; range = 2.6 to 5.3 mins) (37.0 ± 0.5°C, 36.9 ± 0.1°C, 37.1 ± 0.4°C for NC, HC and FC trials respectively). Pairwise comparisons from start to end of performance show that for those trials where performance time exceeded five minutes (n=14; range = 5.6 to 13.4 mins), $T_{au}$ significantly increased from post-cooling to the end of the performance trial (37.4 ± 0.5°C, 37.1 ± 0.3°C, 37.5 ± 0.1°C) for NC, HC and FC respectively ($P<0.05$). This is likely due to the longer duration of performance creating a greater amount of metabolic heat and therefore resulting in a greater increase in $T_{au}$. Indeed, pairwise comparisons demonstrated no significant differences in $T_{au}$ between trials at 35 or 40 minutes, indicating that the longer duration allowed for the greater increases in $T_{au}$ thereafter.

## 5.2 Skin Temperature

There was no significant interaction for MST between the three trials. As with the other temperature measurements MST significantly rose during the initial 20 minutes of exercise but was not observed to be significantly different between the three trials. The data for $T_{re}$, $T_{au}$ and MST all show no significant differences between trials in the initial 20 minutes of exercise indicating that levels of thermal strain were equal in all trials before the commencement of the cooling period. The absence of differences between trials during cooling may be due to the incorporation of $T_{th}$ and $T_{ca}$ into the MST formula. This may dampen the increases of $T_{ch}$ as the lower body measurements demonstrate a smaller increase ($T_{th}$ = 3.5°C; $T_{ca}$ = 1.1°C) compared to the upper body ($T_{ch}$ = 5.7°C; $T_{arm}$ = 6.0°C) due to the relative lack of muscle activity in the lower body.

This, combined with a large variation between participants, could therefore account for the lack of statistical significance observed for MST between trials.

The incorporation of non-exercising areas of the thigh and calf within the MST calculation is important. Despite being relatively inactive during upper body exercise the peripheral circulation in the lower body will still vasodilate in order to maximise whole body heat loss. This is in keeping with results found by Johnson and Rowell (1975) and Wyss et al. (1975) where, via plethysmography, they describe the decrease of muscle blood flow to the non-exercising limb whilst observing a significant increase in total blood flow to the area. This increase in skin blood flow would result in increased local skin temperature as a greater volume of warmed blood would be flowing through the skin in order to dissipate the heat from the core. This is supported by the results for increases in local blood flow in the current study as the increases in skin blood flow become less marked at lower regions of the body (back = ~2000%; thigh = ~1100%; calf = ~ 620%). In addition, using the Laser Doppler technique employed in the current study, Muraki et al. (1995) and Theisen et al. (2001) observed significant increases in leg skin blood flow during upper body exercise. An increase of approximately 200% at the thigh was observed by Muraki et al. (1995) after 6 minutes of exercise at 50W whilst Theisen et al. (2001) observed an increase of approximately 150% at the calf after just 2 minutes of exercise at 80% maximal capacity. Allowing for the differences in exercise intensity between these studies and the current study the results are certainly comparable. In the current study an increase of approximately 600% was observed at the thigh and approximately 425% at the calf after 5 minutes of upper body exercise at 65% peak power.

A significant effect of HC on $T_{arm}$ was observed but there were no significant interactions for $T_{ch}$, $T_{th}$ or $T_{ca}$. Both $T_{ch}$ and $T_{arm}$ demonstrated a significant increase over time whereas $T_{th}$ and $T_{ca}$ did not. This is likely due to the relative levels of involvement in the exercise between the sites. Arm and chest muscles form a large part of the exercising muscle mass during arm crank exercise and as such will produce a large amount of metabolic heat. Therefore it stands to reason that $T_{ch}$ and $T_{arm}$ would demonstrate larger increases over time than $T_{th}$ and $T_{ca}$. Furthermore the exercising areas will experience increases in muscle blood flow in order to supply fuel to the exercising tissues. As a result a larger volume of warm blood would be flowing through the area during exercise compared to the legs, therefore resulting in warmer skin temperatures in the upper arm and chest when compared to the lower body measurements.

Local blood flow responses may contribute to the effect of HC on $T_{arm}$. As the blood flow of the site has risen during exercise there would be a greater potential for heat loss from the site during cooling, providing that blood flow remains elevated during cooling. As the cooled blood from the hands flowed back through the arms, heat could be more efficiently transferred, due to a combination of heat gradient and blood volume, from the arm muscles to the blood and subsequently the environment in the same way heat is dissipated from the body core. The typically larger surface area to mass ratio of the arms compared to the legs (Sawka, 1989) would also aid the process. During FC however, the cooled blood would not be flowing through the arms as it returns from the feet and as a result the arm muscles cannot transfer as much heat to the blood due to the smaller temperature gradient between the muscle and the blood. Cooling for the upper body in this instance would be reliant on the decrease in metabolic heat production during recovery compared to exercise. The same would apply for the intervention period in NC, as there is no active cooling being applied there is simply warmed blood continuing to flow through the arms and as such $T_{arm}$ does not decrease significantly.

## 5.3 Heat Loss

A significantly greater amount of heat was lost from the hands than from the feet even though core temperature was the same in each trial. Previous studies have demonstrated the effects of using either the hands (Livingstone et al., 1989; House et al., 1997) or the feet (Livingstone et al., 1995) to facilitate cooling but have not been compared within the same study. Livingstone et al. (1995) demonstrated a slightly greater heat loss from the feet (151W at a water temperature of 10°C) compared to with the hands (124W at a water temperature of 10°C) (Livingstone et al., 1989) for a lower body exercise protocol. When compared to the current study of upper body exercise these results are reversed in that heat loss from the hands was 140W and from the feet was 121W. This may be an indicator of the localised effects of exercise mode on heat loss potential. The greater effectiveness of FC in a lower body exercise protocol compared to an upper body exercise protocol may well be due to the metabolic heat production from the lower body. This would then provide greater heat loss potential from the feet which is not present during an upper body exercise protocol. Furthermore, in both of the Livingstone et al. studies, part of the protocol involved cooling during exercise rather than in a rest period following exercise. This would allow for greater circulation of cooled blood from around the extremities as the effects of physiological responses to exercise are maintained.

When comparing the Livingstone et al. (1995) data, which was obtained from a resting protocol, it can be observed that, for the 10°C water temperature cooling trial, the heat loss from the hands (99W) was a great deal lower than from the feet (151W). Conversely, the results observed in the current study demonstrate that during a rest period, following 20 minutes of upper body exercise in the heat, FC is a less effective method for heat dissipation or alleviation of an increased $T_{au}$ than HC. From the current data HC is a more effective mode of heat dissipation following upper body exercise. Certainly, the dissipation of heat is imperative to attenuating the physiological effects of heat strain and the observed benefits of HC over FC should be considered potentially beneficial during upper body exercise. It should be noted that the cooling data from Livingstone et al. (1995) was not reported following an exercise protocol and therefore it is likely that the use of upper body exercise prior to cooling in the current study enabled a greater effect of cooling from the hands.

## 5.4 Heat Flow

Although there were differences between HC and FC for total heat loss the results for heat flow during cooling demonstrated no significant differences. However a trend demonstrated less heat flow from the hands during the first ten minutes of cooling. This would appear to be in contrast to the results for total heat loss. One possible explanation is that a large part of the total heat loss from the hands occurred in the first five minutes of cooling prior to measurement. Therefore when the heat flow measurements were taken after five minutes of cooling the majority of the heat loss from the hands may have already occurred. As a result heat flow could be recorded as greater in the feet than the hands after five minutes of cooling as the cooling gradient between the feet and the water was still elevated. This would occur because heat flow is a measurement of heat exchange between two surfaces (i.e. the skin and the water) with the greater the gradient between the two surfaces the larger the heat flow. The more heat a surface loses the smaller the gradient and the slower the heat flow. Indeed, the results observed for hand and foot temperature during cooling suggest the majority of cooling to have occurred in the first 5 minutes of the cooling period. Following this hand and foot temperature demonstrate very little fluctuation during the remainder of the cooling period. This indicates that heat flow after 5 minutes of cooling will be much lower.

Similarly, House et al. (1997) observed $T_{au}$ to decrease rapidly (~1°C) in the first ten minutes of hand cooling in water at 10°C before beginning to plateau for the remaining 20 minutes. The differences in protocol may explain why the current study did not see similar results with $T_{au}$. House et al. (1997) exercised participants until a cut off point of 38.5°C for a maximum of 40 minutes prior to cooling. In the current study exercise time was the fixed factor and $T_{au}$ values reached prior to cooling were much lower (37.5°C) and as such the drive for heat loss from $T_{au}$ was much lower than for House et al. (1997) leading to a less effective cooling response. Furthermore, there was a significantly greater decrease in skin temperature for the hands (~24°C) compared to the feet (~18°C) throughout the cooling period. After 15 minutes of cooling, however, heat flow from the hands and feet appears very similar (HC = 95$W \cdot m^{-2}$; FC = 106$W \cdot m^{-2}$) indicating that the majority of heat loss from the hands must have occurred in the first five minutes of cooling. Furthermore, hand skin temperature only decreased a further 1°C after 15 minutes but was still greater than water temperature indicating no cutaneous vasoconstriction (House et al., 1997).

## 5.5 Performance Time

No significant differences were found for performance time between the three trials. There was a trend for a longer performance time after HC than both NC (+96s, improvement of 24%) and FC (+101s = improvement of 26%). NC and FC were almost identical with mean times of 395s and 391s respectively. There was a trend for all participants to perform for longer following HC than NC with improvements ranging from 57 to 181 seconds. This trend corresponds with that for $T_{au}$ during cooling as the lower $T_{au}$ will improve the heat storage capacity of the body and increase the time taken to reach a critical core temperature (Marino, 2002). This then enables a greater endurance performance time. A wide variation in performance was observed in the $\dot{V}O_{2pk}$ tests (range = 110W to 192W) in the current study, which is further reflected in the performance trial times for NC (range = 221s to 747s). The trend for improvements in performance following HC is partly in agreement with the results of Goosey-Tolfrey et al. (2008) when considering their able-bodied group data where significant performance improvements were observed after HC compared with control (decrease of 14s from 281s in 3km time trial = 5% improvement). However, this improvement was much lower than in the current study.

One possible reason for the lack of significance between trials for performance time in the current study is the large variability in the time trial data. Indeed, the data across all three trials ranged from 155s to 804s and standard deviations were 205s, 190s, and 157s for NC, HC and FC respectively. This could be due to possible differences in training status between the participants, which is also reflected in the range of peak power outputs (110W to 192W) and $\dot{V}O_{2pk}$ values (2.3 to 3.9 $l \cdot min^{-1}$) from the preliminary $\dot{V}O_{2pk}$ trials. The $\dot{V}O_{2pk}$ values correspond with the means observed by Sawka et al. (1984) ($2.5 \pm 0.4$ $l \cdot min^{-1}$) and Price and Mather (2004) ($3.1 \pm 0.5$ $l \cdot min^{-1}$). Peak power outputs were greater than the mean observed by Goosey-Tolfrey et al. (2008) ($81 \pm 39$W) as may be expected for wheelchair athletes based on the lower functional muscle mass available, although the large standard deviation indicates a similar variability to the current study. However, in the current study, the participants with the highest peak power output and $\dot{V}O_{2pk}$ in the $\dot{V}O_{2pk}$ test did not always produce the longest performance times. This could indicate a greater prevalence of psychological and motivational factors affecting performance.

Training status may have an effect on several physiological and thermoregulatory factors, which will aid the participant's endurance exercise performance. Increases in muscle blood flow and oxygen uptake in the upper body musculature are associated with greater training status and will improve endurance exercise performance as a greater supply of oxygen will be coupled with a greater disposal of $CO_2$ (Volianitis et al., 2004). It has been shown that force production during heat strain is impaired to a similar level for highly trained, moderately trained and low trained participants (Morrison et al., 2006). However, the exercise used was an isometric knee extension and as such aerobic training status will not have had as much of an influence as it would on an aerobic endurance exercise protocol. As the exercise protocol in the current study is aerobically based it is likely that differences in the training status of participants will have an effect on exercise performance.

Despite the lack of statistical significance it is encouraging to note that the trends in performance time after HC alongside the results of Goosey Tolfrey et al. (2008) present a promising indicator for improvement of upper body exercise performance in the heat. This data could be particularly useful for those involved in sporting competition requiring a significant upper body component or heavy protective clothing such as American football, rugby, or paddle sports such as rowing and kayaking. However, the possibilities for cooling as presented in this study may not be applicable to sports where regular intervals are not present due to the impracticality of transporting a large body of cooled water.

## 5.6 Skin Blood Flow

No significant interactions were found at any of the sites of skin blood flow between the three trials. Furthermore at the back and thigh there was no significant main effect for skin blood flow over time despite large increases of up to 3000%. This indicates a great deal of individual variation within the results, which would have produced large standard deviation values and therefore no statistical significance. However, there was a significant main effect of time at the calf. This is a further indicator of the increasing of skin blood flow in non-exercising areas to maximise the area for convective heat loss as discussed earlier. This is in keeping with results observed by a number of studies (Johnson and Rowell, 1975; Muraki et al., 1995; Theisen et al., 2001) where skin blood flow as a function of total blood flow was found to increase in non-exercising areas.

One possible reason for the lack of significant increases over time at the thigh and especially at the back is the sensitivity of the laser Doppler probes. The probes measure skin blood flow by measuring the rate of movement of blood cells through the skin microvasculature. Therefore movements of muscle or bone at the site of measurement can easily disturb the probe and result in the recording of movement of the probe on the skin as a change in the rate of movement of the blood cells (Berardesca et al., 2002). This would be particularly true at the back during arm cranking exercise as the scapula moves with the forward rotation of the shoulder girdle. This could lead to increasingly variable values being recorded for skin blood flow and as such large standard deviations in the data could lead to no significance being recorded.

Lower limb skin blood flow has been previously observed to remain unchanged and even decrease slightly, though not significantly, during light arm cranking exercise

(15W increments for 3 minutes each) (Theisen et al., 2001). However, during heavy intensity (80% peak power for 3 minutes) in the same study skin blood flow markedly increased during the final 1.5 minutes (150% from rest, 50% from 1 minute), though with great variability. This is supported by the reported variation of the cutaneous vasodilatory response above a given hypothalamic temperature threshold (Hammel et al., 1963). Therefore the exercise intensities used in the current study of 60% and 75%, combined with the heated environment, may well have been high enough to elicit such variation.

## 5.7 Local Sweat Rate

There were no significant differences observed for local sweat rates between the three trials. There was, however, a significant main effect of time for forehead sweat rate. There was also a trend for sweat rates at each site to decrease more during HC than FC or NC. This corresponds with the trend in the data for $T_{au}$ and demonstrates the importance of $T_{au}$ in the drive for sweating rate. Indeed, the correlation data (Figs. 4.16, 4.17, 4.18 and 4.19) indicates a greater sweat rate with a greater $T_{au}$ therefore with a slightly cooler $T_{au}$ following HC sweat rates would also be slightly lower.

During the first 20 minutes of exercise $SR_F$ increased significantly. This is an indicator of the increased efferent output of the hypothalamus in response to rising core temperature. As $T_{au}$ significantly rose in the first 20 minutes this will have resulted in increased stimulation of the heat loss centre of the hypothalamus via the autonomic nervous system. As a result sympathetic output to sweat glands, and in turn sweat rates, will have increased. The effects of this are represented in figures 21, 22, 23, and 24. This response is accentuated in the forehead due to a greater density of sweat glands (Machado-Moreira et al., 2008) and greater sweat response than other body sites during heat stress (Cotter et al., 1995). Indeed, the results from the current study demonstrate a much greater increase in local sweat rate at the forehead (~1350 $nl \cdot min^{-1}$) than at the back (~850 $nl \cdot min^{-1}$), the thigh (~700 $nl \cdot min^{-1}$) or the calf (~575 $nl \cdot min^{-1}$). This corresponds with the results of Cotter et al. (1995) where forehead sweat rate (3.2 $ml \cdot cm^{-2} \cdot min^{-1}$) was significantly greater than at the thigh (1.0 $ml \cdot cm^{-2} \cdot min^{-1}$) and the calf (1.5 $ml \cdot cm^{-2} \cdot min^{-1}$) during 40 minutes of cycling at 40% peak power in 36.6°C. The difference in sweat gland density in the current study may therefore account for the lack of significant responses from the other sites measured in this study that may require a greater intensity or length of exercise in order to elicit larger responses. Forehead sweat rate significantly decreased during the 15 minutes of cooling in both HC and FC but also in the rest period in the NC trial. As no significant differences were observed between the three trials there is little evidence to suggest any effects of either cooling technique on forehead sweat rate after 20 minutes of upper body exercise.

The back sweat rate values post-cooling were also not significantly different from those experienced during rest. A trend was observed for back sweat rate to have decreased more during HC than FC or NC after 15 minutes of cooling. This trend once again associates with the results for $T_{au}$, which also demonstrate a trend to decrease more during HC than FC or NC.

The differences in local metabolic heat production may also have an effect on heat loss potential. As the muscles utilised in upper body exercise will produce more metabolic heat than the lower body at the same absolute intensity (Sawka et al., 1984) there is then a greater potential for heat loss from the chest and back, as previously described. Indeed, it has been previously shown that local sweat responses are associated with the rate of change in MST (Libert et al., 1979). Therefore a greater rate of cooling caused by a greater drive for heat loss from the chest and back would result in a greater decrease in local sweat rate. This is also hypothesised from the results of Libert et al., (1982). However, skin temperature has also been reported to have no effect on sweat rate and the role of core temperature has been hypothesised as more likely the main factor (Wyss et al., 1974). This is in accordance with the results of the current study for forehead sweat rate as the significant decrease during cooling is coupled with a decrease in $T_{au}$ but not in MST across all three trials. We can therefore note that $T_{au}$ would have been the greater factor in instigating changes in local sweat rates than skin temperature in the current study.

## 5.8 Respiratory Variables

Neither HC nor FC was observed to have any significant effects on $\dot{V}O_2$, $\dot{V}CO_2$, VE or RER during exercise following cooling. This is in keeping with results observed previously in this area (Price and Mather, 2004). Mean $\dot{V}O_2$, $\dot{V}CO_2$ and VE were slightly lower at the end of performance trial than the peak values from the $\dot{V}O_{2pk}$ test. This indicates that participants may not have reached cardio-respiratory exhaustion in the performance trial. There was, however very little difference in RER between $\dot{V}O_{2pk}$ test (0.97) and experimental trial values (1.01). In addition, local RPE was consistently reported at between 18 and 20 at the end of performance trial, which would indicate that participants at least perceived that they were exercising at maximal capacity. There could be disparity between perceived and actual exertion due to psychological factors. When using volitional exhaustion as a cut off point there is likely to be a motivational factor involved. If participants are finding the exercise unpleasant, but not necessarily exhaustive, then they may stop exercising earlier than they would if they were in more comfortable conditions. This is indicated in the significant increases in TS observed throughout the first exercise period and the performance trial. It should be noted, however, that RPE for the arms and upper body for the majority of participants was reported as 20 at the end of both the $\dot{V}O_{2pk}$ test and experimental trials. This demonstrates that whilst participants may not have reached absolute exhaustion they did perceive that they had. Furthermore, combined with the RER results this indicates a localised fatigue rather than absolute aerobic fatigue. The RER values indicate that participants are performing at similar exercise intensities at the end of both the performance trial and the $\dot{V}O_{2pk}$ test.

Blood lactate levels significantly increased at the end of the performance trial but there were no significant differences between NC, HC and FC. There was however a slight trend for both cooling methods to reduce maximal blood lactate levels (1.4 mmol for HC and FC) compared to NC (2.8 mmol) during cooling. This indicates that the cooling methods may have facilitated an increase in lactate oxidation during cooling. Indeed, other studies have demonstrated significant decreases in lactate with a recovery technique involving cooling than with no cooling (De Pauw et al., 2010). Mean lactate levels at the end of the performance trial were not significantly different from those observed at the end of the $\dot{V}O_{2pk}$ tests. There was, however, a trend for values to be lower at the end of performance trial (5.5 ± 2.3 mmol, 6.1 ± 0.9 mmol and 5.7 ± 1.6 mmol for NC, HC and FC respectively) than at the end of the $\dot{V}O_{2pk}$ tests (7.7 ± 1.3mmol). Whilst the statistics demonstrate no significant difference it does appear that participants may not have reached absolute exhaustion at the end of the performance trial.

No significant differences were seen for HR between the three trials at any time point. The similar values during the three experimental trials in the initial 20 minutes of exercise demonstrates that the participants were working at a similar intensity and that similar experimental conditions were maintained across all three trials before any intervention had taken place. There was no significant effect of cooling on HR. This is in accordance with previous literature examining hand or foot cooling where no effects on HR have been reported (Livingstone et al., 1989; Livingstone et al., 1995; House et al., 1997). However, lower body cooling has been observed to elicit a significantly lower HR than upper body cooling during exercise (Price and Mather, 2004). Maximal HR was slightly lower at the end of performance trials than at the end of $\dot{V}O_{2pk}$ tests. This could indicate that oxygen supply to the working muscles is not the limiting factor in continuous upper body exercise performance in the heat.

## 6.0 Conclusion

In conclusion, this study intended to describe and compare the effects of hand and foot cooling on thermoregulation and exercise performance during upper body exercise in the heat. From the results observed a number of trends have been demonstrated which indicate possible benefits of HC on alleviating heat strain following 20 minutes of upper body exercise in the heat. It was hypothesised that both HC and FC would significantly increase heat loss and reduce core temperature compared to NC. The data presented here for $T_{au}$ demonstrated a trend for HC to be more effective at alleviating core temperature increases compared to NC, which is in accordance with results observed by House et al. (1997). Heat loss was observed to be greater during HC than FC or NC which, combined with a significantly lower $T_{arm}$ following HC, demonstrates a greater localised cooling response than for FC or NC. Therefore the hypothesis that HC would result in greater heat loss than NC was met, however for FC it was not. The hypothesis that HC and FC would result in a significant reduction in core temperature compared to NC was also not met despite the trend observed for HC.

To date there has been little investigation of the comparative effects of HC and FC on heat loss. Here we observed HC to result in significantly greater heat loss than FC during a 15 minute cooling period. We can therefore suggest that HC is an effective method for increasing heat loss from the hands following 20 minutes of exercise in hot conditions. This information could be applied to certain scenarios as mentioned before such as during rest periods of sports matches or between rounds during events. This data could also be of particular interest to wheelchair athletes as their events require a large component of upper body exercise and the redistribution of blood is disturbed below the lesion, therefore not favouring FC (Hopman et al, 1993).

It was hypothesised that HC would result in a significant improvement in exercise performance compared to NC. Whilst HC did result in improvements in subsequent submaximal upper body exercise performance compared to NC for all participants, this was not shown to be significant and thus the hypothesis was not met. In terms of application to sporting competition, the significance of an improved performance time is dependant on the average completion time of the event. An improvement of 96s as noted here could be incredibly beneficial during short-to-medium duration events. It would be beneficial for further studies to examine the effects of training status on the ability to lose heat via HC and FC. This would provide an insight into the benefits of HC and FC for more highly trained athletes. It would also be interesting to note how this then affects the subsequent exercise performance of specifically upper body trained individuals. It is clear that a significant gap in the literature remains for the comparative effects of HC and FC on exercise for able-bodied populations in the heat. Furthermore, considering the small amount of data available describing effects of HC and FC on upper body exercise performance, it would be incredibly beneficial for further studies to examine these effects.

## 7.0 Implications for Sporting Performance

While observing the effects of HC and FC on thermoregulation it is important to consider how these methods can be applied in a sporting context. Firstly these methods can only be practicable in sports where significant breaks are involved as a significant cooling effect requires around 10-15 minutes. Certain team sports such as rugby, football and American football could utilise HC or FC during intervals or whilst players are resting. Reducing an increased core temperature in these sports could be vital in maintaining the internal conditions required for optimum metabolic enzyme activity and therefore optimum physical performance. HC could be considered slightly more practical in these situations than FC as it does not require the removal of any clothing which maximizes the time that the cooling can be applied. The significant decrease in $T_{arm}$ observed in the current study could certainly be beneficial to participants in sports requiring upper body exertion as the lower temperature will increase the time to exhaustion of the local muscle groups and maintain the optimum conditions for local metabolic enzymes. However, HC may cause a loss in manual dexterity that could affect performance in those sports requiring hand control. There is also a possibility that the discomfort caused by the cooling methods (as reported by a number of participants in the current study) could distract the athletes from tactics or instructions being discussed in the intervals.

HC and FC may also be applied in between rounds of sporting competitions. Events such as kayaking or athletics events that involve qualifying heats may require athletes to perform multiple rounds in a short space of time. Therefore during the interim period HC or FC could be applied in order to alleviate any thermal strain from the previous rounds and aid recovery. As these breaks may also be longer than those in many team sports this provides more time to remove footwear or other protective clothing and extra time to apply cooling. In addition, the extra time would mean that athletes do not necessarily need to immediately begin competition following cooling, eliminating the possibility of entering into competition whilst still experiencing the discomfort of the cooling methods.

The cooling methods as they appear in the current study may not necessarily be directly applicable to the wider sporting community due to the complications in transporting a large body of water and maintaining it at the correct temperature. In addition, the difficulties in applying the method in short intervals without disrupting other preparations would likely result in many teams and coaches discarding the idea. However, the trends in the data represent an inviting prospect for sporting participants as the lowering of core temperature and increase in endurance capacity will be great advantages for the majority of athletes. Therefore if the current methods could be adapted so that application of them is less disruptive and more comfortable to undergo then they would be of significant benefit to a large number of athletes.

## 8.0 Limitations

As previously stated the participants in the current study did not reach core temperatures as high as in previous studies (Livingstone et al., 1989; Livingstone et al., 1995; House et al., 1997) in the first 20 minutes of exercise. This may have then contributed to the diminished effects of cooling on core temperature that were observed. Whilst the exercise duration was reduced due to reported difficulties of maintaining 60% peak for 30 minutes it would have been beneficial to reduce the intensity rather than the time. This would provide more time for core temperature to increase via radiation from the environment rather than relying on metabolic heat production from a higher intensity of exercise. With a higher core temperature there would then be a greater drive for heat loss and significant effects of cooling on core temperature may be observed.

The large variation in certain variables, particularly in performance time, is likely a contributing factor to the lack of statistical significance found. This could perhaps be alleviated with a larger number of participants and a greater familiarisation or training aspect prior to the experimental trials. However, it should be noted that previous studies in this area have demonstrated significant results whilst using six (Livingstone et al., 1995), five (Livingstone et al., 1989) and four participants (House, 1997). Therefore the use of seven participants in the current study could have yielded statistical significance if not for the large variation in results for some variables between participants. In addition, as participants acted as their own controls this also reduces the overall number of participants compared to studies that use an experimental and control group (Goosey-Tolfrey et al., 2008).

Heat flow was not measured during the exercise period due to participant discomfort and also the difficulties in keeping heat flow sensors attached. As the sensors were required to be placed across the back of the hands and were not flexible the exercising action would have easily displaced them and the rigid design would have been particularly uncomfortable for the participant. Furthermore, when the hands are clenched to grasp the ergometer handles the back of the hand is no longer flat and as such the disks would not be completely in contact with the skin, resulting in inaccurate readings. As noted in section 5.4, the majority of heat flow appeared to have occurred in the first five minutes of cooling. It would therefore be ideal to take heat flow readings every minute during the first five minutes of cooling in order to observe the effects of HC and FC on heat flow more closely. Moreover it would be greatly beneficial to include skin blood flow readings of the hands and feet during cooling. This would provide additional data alongside heat flow and temperature readings that could be used to more accurately interpret the effects of HC and FC on heat loss and heat flow. Skin blood flow of the hands and feet during cooling could be provided if a method of water-proofing the Laser Doppler probes was implemented. It may be possible to cover the probe, or indeed the whole hands or feet, in a plastic bag which would still allow for heat flow between the water and the hands or feet but keep them and the probe dry.

## 8.1 Future Research

With reference to the limitations of the current study it would be beneficial for further research to look at a longer exercise period to increase core temperature. To offset the fatigue reported by participants it may be advantageous to reduce the initial intensity and increase the exercise time. Alternatively it may be beneficial to adapt the protocol to include a core temperature cut off point rather than a time constraint for the initial exercise period. With this method there would be more control over core temperature prior to cooling and therefore a more likely significant cooling effect. However, it should be noted that this method may result in participants exercising for significantly different durations and this could then affect the results for the performance trial. It may therefore be advantageous to consider a maximum duration in addition to the core temperature cut off as seen in the study by House (1997).

It would be further beneficial for future research to focus on larger participant groups. This would offset the variations in the data that were observed in the current study and would increase the likelihood of statistically significant results. It is also important to note that, as previously mentioned, a large section of the literature relating to hand and foot cooling has used particularly small participant groups (Livingstone et al., 1989;

Livingstone et al., 1995; House, 1997). The high training status of the participants used in these studies may contribute to a very small variation in results and therefore lead to significant results being recorded. When focussing on participants with different training statuses it is likely that greater variation will occur and so a larger number of participants will be required for statistical significance in the data.

Future research should also consider the advantages of recording skin blood flow during the cooling period. Whilst heat flow was recorded during cooling in the current study, it was only possible to record this data periodically, which does not necessarily provide a complete analysis of the cooling effect. If laser Doppler information was also recorded during cooling then this would provide a thorough analysis of the entire cooling period. This would then enable a more accurate interpretation of the data particularly as it seems from the current study the majority of total heat flow has already occurred during the first five minutes of cooling. Whilst heat flow and heat loss data provide a good indication of the overall cooling effect during the cooling period, the addition of skin blood flow data would enable a more accurate description of the optimum conditions for cooling and therefore enable more accurate development of cooling techniques.

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# 10.0 Appendices

Appendix A – University Ethics Committee Approval Form

**REGISTRY RESEARCH UNIT**
**ETHICS REVIEW FEEDBACK FORM**
**(Please return to Registry Research Unit within 10 working days)**

Name of applicant and Faculty/School: NICHOLAS SAXTON (HLS)

Research project title: The effect of hand + foot cooling on upper body exercise in the heat.

Comments by the reviewer

1. Evaluation of the ethics of the proposal:

Interesting study that is well designed. Research group are very experienced in this type of work. Needs to include bit more information (see below).

2. Evaluation of the participant information sheet and consent form:

These are fine.

3. Recommendation:
(Please indicate as appropriate and advise on any conditions. If there any conditions, the applicant will be required to resubmit his/her application and this will be sent to the same reviewer).

☐ Approved - no conditions attached

☐ Conditional upon the following – please use additional sheets if necessary

PLEASE INCLUDE INFORMATION ON TEMPERATURE OF THE FOOT/HAND COOLING WATER.

☐ Rejected for the following reason(s) – please use other side if necessary

☐ Further advice/notes - please use other side if necessary

**Name and signature of reviewer:** [illegible]
**Date:** 9/3/09

Appendix B – Informed Consent Form

**FACULTY OF HEALTH AND LIFE SCIENCES**
**Department of Biomolecular and Sports Sciences**

# THE EFFECTS OF HAND VS. FOOT COOLING ON UPPER BODY EXERCISE IN THE HEAT.

**Principal Investigator:** **Nicholas Saxton**
**Principal Supervisor:** **Dr Mike Price**

Thank you for showing interest in participating in this study. It is important that before you volunteer to participate you are absolutely clear on the intentions of the study and the protocol involved. All the relevant information is provided below and requires your close attention prior to your participation. Do not hesitate to ask any questions that you may have regarding information provided here or other queries you may have.

## PURPOSE OF THE RESEARCH

This study aims to compare the effects of hand and foot cooling techniques on upper body exercise in hot temperatures. Hand and foot cooling by submergence in cool water have both been shown to efficiently decrease elevated core temperatures but only hand cooling has been used in an exercise protocol. This study will look at whether hand and foot cooling can significantly decrease the hyperthermic effects of exercise in hot climates and improve exercise performance when compared with no cooling.

## PARTICIPATION IN THIS RESEARCH WILL INVOLVE

If you volunteer to participate in this study you will be required to visit the lab on 4 separate occasions. The first visit will involve a maximal arm cranking test using a mechanically braked Lode Arm Crank Ergometer. You will undergo a graded exercise test to exhaustion to determine your peak oxygen uptake ($VO_{2pk}$) and peak power. All 3 of the following visits will take the form of an initial exercise period of around 30 minutes, or until core temperature reaches 39.5$^{o}$C, where you will arm crank at 60%$VO_{2pk}$ at 40$^{o}$C. You will then rest for 15 minutes with 1 of 3 conditions – hand cooling; foot cooling; or no cooling. Hand and foot cooling will require you to place your hands or feet in water at 10°C for the 15 minute period. After this period you will then perform a steady state exercise period at 75%$VO_{2pk}$ until volitional exhaustion. Exhaustion shall be taken as the point at which you either voluntarily cease exercise or are unable to maintain the required intensity for a significant time period (~5 secs max). There will then follow a 10 minute recovery period in which you will remain sitting and resting.

Skin and core (rectal and aural) temperatures will be continuously monitored throughout the entire protocol. Skin blood flow, temperature, sweat rates and heat flow shall all be measured at 4 sites – centre of the forehead; the right shoulder blade; centre of the thigh; and the centre of the lateral side of the calf. Skin blood flow will be measured using a Laser Doppler Flowmeter, skin temperature using thermistors, sweat rates using a quantitative sweat measurement system (Q-sweat) and heat flow using heat flow disks. All of these are non-invasive instruments that are simply placed on the surface of the skin and stuck on with tape. Core temperatures will be measured using a rectal thermistor, inserted 10cm beyond the anal sphincter, and an aural thermistor inserted into the ear canal. Heart rate will be measured using a Polar heart rate monitor and chest strap and breath by breath values for VE and RER will be measured using a breath sampling system which requires the wearing of face mask covering the nose and mouth throughout the whole trial. Blood samples will be taken from the ear lobe using an automatic lancet at 5 minute intervals, which will be used to measure blood lactate levels.

**FORESEEABLE RISKS OR DISCOMFORTS**
There is a possibility that you may experience discomfort from exercising in the heat but this will only manifest itself in the form of effects you will have felt before from strenuous exercise. You may also feel a little discomfort from the blood sampling technique but this is only a short pin prick on the ear lobe.

## DATA PROTECTION

Any information provided in questionnaires, along with all your data, will be kept strictly anonymous. Paperwork will be stored in a locked filing cabinet and data will be kept on a password-secured computer only accessible to the principal investigators, i.e. Nicholas Saxton and Dr. Mike Price. Your name will never used in conjunction with your data as each data set will be stored under a code.

**If you have any further questions regarding your participation in this study please do not hesitate to ask Nick Saxton – saxtonn@coventry.ac.uk or Dr. Mike Price.**

If you have any questions about your rights as a participant or feel you have been placed at risk you can contact Dr Mike Price.

I confirm that I have read the above information. The nature, demands and risks of the project have been explained to me.

I have been informed that there will be no benefits / payments to me for participation

I knowingly assume the risks involved and understand that I may withdraw my consent and discontinue participation at any time without penalty and without having to give any reason.

Subject's signature ____________________________________Date _____________

Investigator's signature ____________________________________Date _____________

**The signed copy of this form is retained by the student, and at the end of the project passed on to the supervisor.**
A second copy of the consent form should be given to the subject for them to keep for their own reference.

Appendix C – Subject Information Sheet

# THE EFFECTS OF HAND VS. FOOT COOLING ON UPPER BODY EXERCISE IN THE HEAT.

**Investigator:** Nicholas Saxton
**Principal Supervisor:** Dr Mike Price

Thank you for showing interest in participating in this study. It is important that before you volunteer to participate you are absolutely clear on the intentions of the study and the protocol involved. All the relevant information is provided below and requires your close attention prior to your participation. Do not hesitate to ask any questions that you may have regarding information provided here or other queries you may have.

**BY ANSWERING OUR QUESTIONS YOU ARE CONSENTING TO YOUR DATA BEING USED IN THIS STUDY. NO RECORD WILL BE MADE OF YOUR NAME SO INFORMATION IS STRICTLY ANONYMOUS.**

## What is the purpose of the study?

This study aims to compare the effects of hand and foot cooling techniques on upper body exercise in hot temperatures. Hand and foot cooling by submergence in cool water have both been shown to efficiently decrease elevated core temperatures but only hand cooling has been used in an exercise protocol. This study will look at whether hand and foot cooling can significantly decrease the hyperthermic effects of exercise in hot climates and improve exercise performance when compared with no cooling.

## What does it involve?

*Protocol:* Participants will report to the lab on 4 separate occasions. The first visit will involve a maximal arm cranking test using a mechanically braked Lode Arm Crank Ergometer. The participant will undergo a graded exercise test to exhaustion to determine their peak oxygen uptake ($VO_{2pk}$) and peak power. All 3 of the following visits will take the form of an initial exercise period of around 30 minutes, or until core temperature reaches 39.5°C, where the participant will arm crank at 60%$VO_{2pk}$ at 40°C. Participants will then rest for 15 minutes with 1 of 3 conditions – hand cooling; foot cooling; or no cooling. Hand and foot cooling will require submergence of the relevant extremities in a container of water at 10°C. After this period they will then perform a steady state exercise period at 75%$VO_{2pk}$ until volitional exhaustion. Exhaustion shall be taken as the point at which the participant either voluntarily ceases exercise or is unable to maintain the required intensity for a significant time period (~5 secs max). There will then follow a 10 minute recovery period in which the subject remains sitting and resting.

*Measurements:* Skin and core (rectal and aural) temperatures will be continuously monitored throughout the entire protocol. Skin blood flow, temperature, sweat rates and heat flow shall all be measured at 4 sites – centre of the forehead; the right shoulder blade; centre of the thigh; and the centre of the lateral side of the calf. Skin blood flow will be measured using a Laser Doppler Flowmeter (Moor Instruments), skin temperature using thermistors, sweat rates using a quantitative sweat measurement system (Q-sweat) and heat flow using heat flow disks. Core temperatures will be measured using a rectal thermistor, inserted 10cm beyond the anal sphincter, and an aural thermistor inserted into the ear canal. Heart rate will be measured using a Polar heart rate monitor and chest strap and a cosmed K4 analyser will be used to record breath by breath values for VE and RER. Blood samples will be taken using an automatic lancet (Softclix) at 5 minute intervals and blood lactate measurements will be analysed using a Biosen blood sample analyser.

## What do I have to do?

Participants will be required to report to the lab at the same time of day for each experimental trial in order to avoid any confounding circadian effects on the data.

## Do I have to take part?

Participation is entirely voluntary. Participants are fully entitled to opt out of the study at any point even after having already attended for 1 or more of the trials, without reason. A consent form must be obtained from the participant by the investigator before any trials can take place.

## What are the possible disadvantages or risks in taking part?

Due to the combination of high ambient temperature and strenuous exercise skin and core temperatures must be closely monitored and exercise will be stopped if core temperature should reach $2^{o}C$ above resting value in order to prevent heat stress injuries or illness occurring. Heart rate will also be closely monitored throughout exercise and ratings of thermal comfort, thermal sensation and perceived exertion will be recorded at 5 minute intervals. Dehydration may also be a significant risk and so subjects will be allowed and encouraged to take on fluids where necessary. Required fluid intake can be deduced using the sweat rate measurements, which will indicate the amount of fluid loss.

## What will I get out of the study?

You will gain an insight into the investigative methods used in the laboratory. You will also have information on your specific upper body fitness from the exercise performed. Furthermore, you may ask questions about the scientific aspects of the study and you may find it interesting what we are trying to achieve.

## Who has reviewed the study?

The ethics committee in the Health and Life Science department at Coventry University has approved the study.

**If you have any further questions regarding your participation in this study please do not hesitate to ask Nick Saxton – saxtonn@coventry.ac.uk or Dr. Mike Price.**

Appendix D – Borg scale of perceived exertion (Borg, 1970)

This item has been removed due to third party copyright. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.

Appendix E – Thermal Sensation scale (Young et al., 1984)